CHAPTER 25
PLANTS 1

Key Topics:

- Ancestry and Diversity of Modern Plants
- The Evolutionary History of Land Plants
- The Origin and Evolutionary Importance of the Plant Embryo
- The Origin and Evolutionary Importance of Leaves and Seeds

Ancestry and Diversity of Modern Plants

Kingdom Plantae

Multicellular, photosynthetic, eukaryotic organisms composed of cells having plastids (e.g. chloroplasts)

Primarily live on land

Evolved from green algal ancestors that lived in aquatic habitats

Distinguished from modern algal relatives by adaptations to terrestrial life

HORSETAILS (*EQUISETUM* SP.)

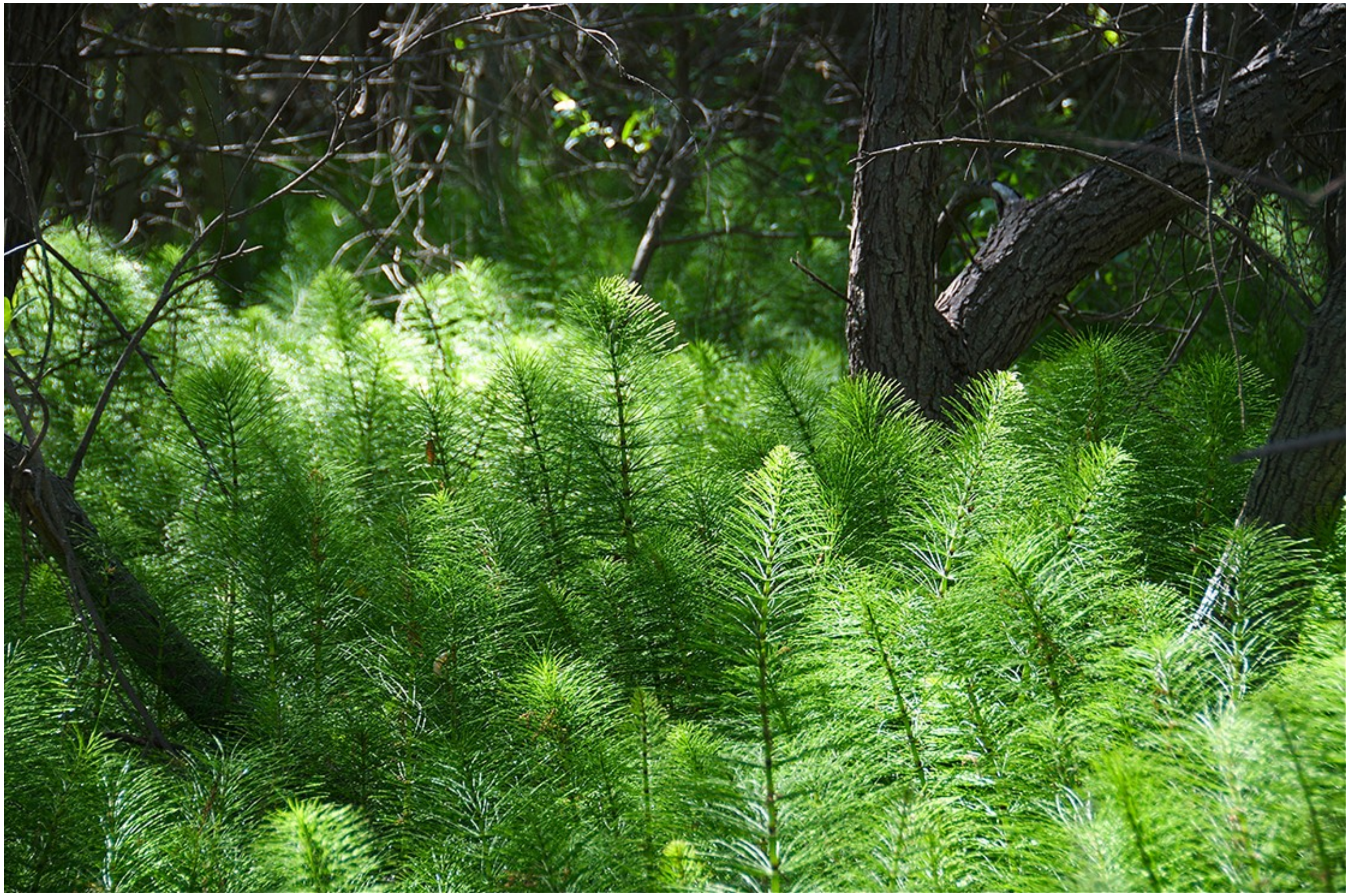

Figure 1. Seedless plants, like these horsetails (Equisetum sp.), thrive in damp, shaded environments under a tree canopy where dryness is rare. (credit: modification of work by Jerry Kirkhart)

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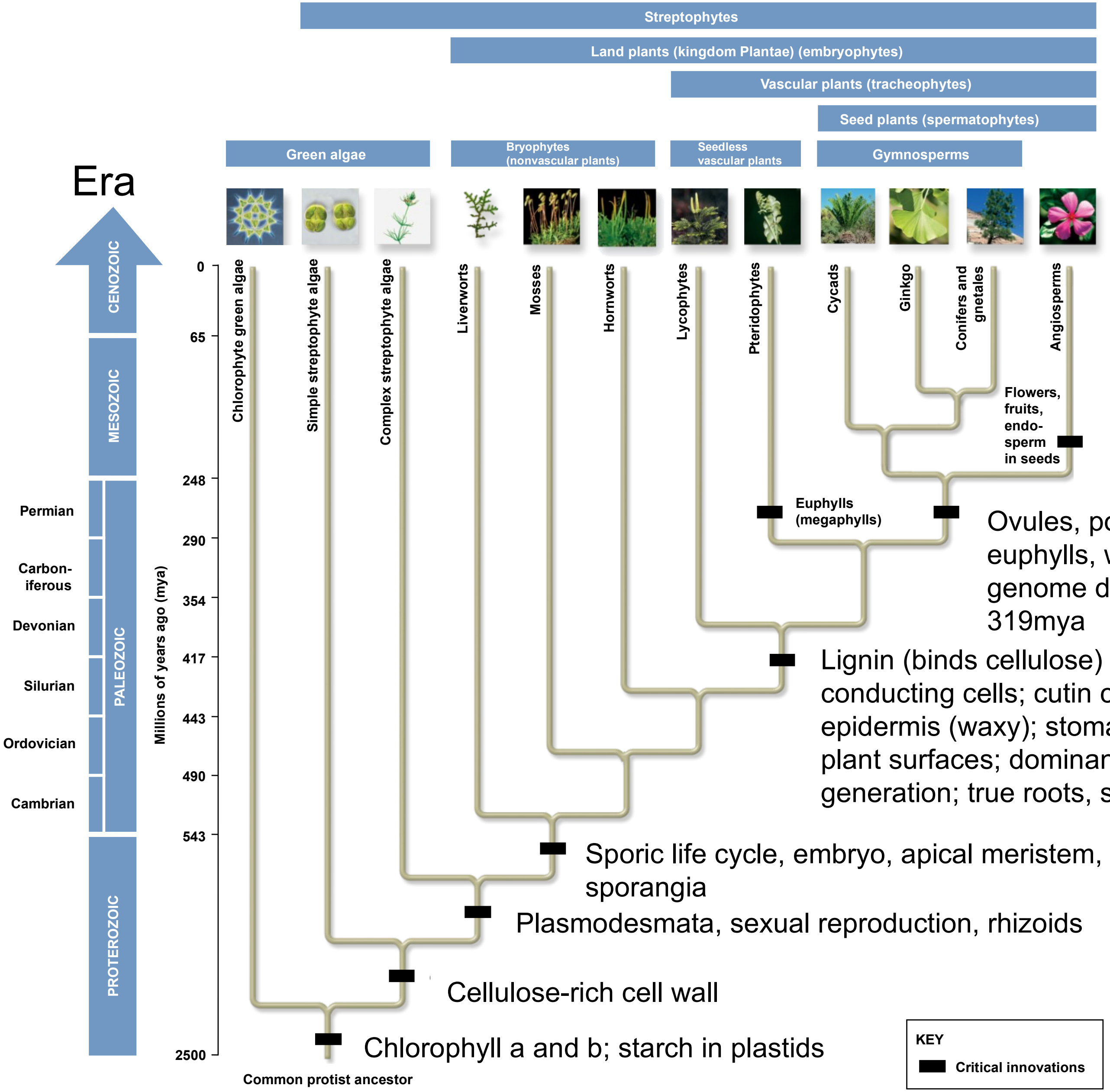
Era



Flowers, fruits, endosperm in seeds

Ovules, pollen, seeds, euphylls, wood, whole genome duplication event 319mya

Lignin (binds cellulose) in walls of water-conducting cells; cutin common on epidermis (waxy); stomata common on plant surfaces; dominant sporophyte generation; true roots, stems, leaves

Sporic life cycle, embryo, apical meristem, gametangia, sporangia

Plasmodesmata, sexual reproduction, rhizoids

Cellulose-rich cell wall

Chlorophyll a and b; starch in plastids

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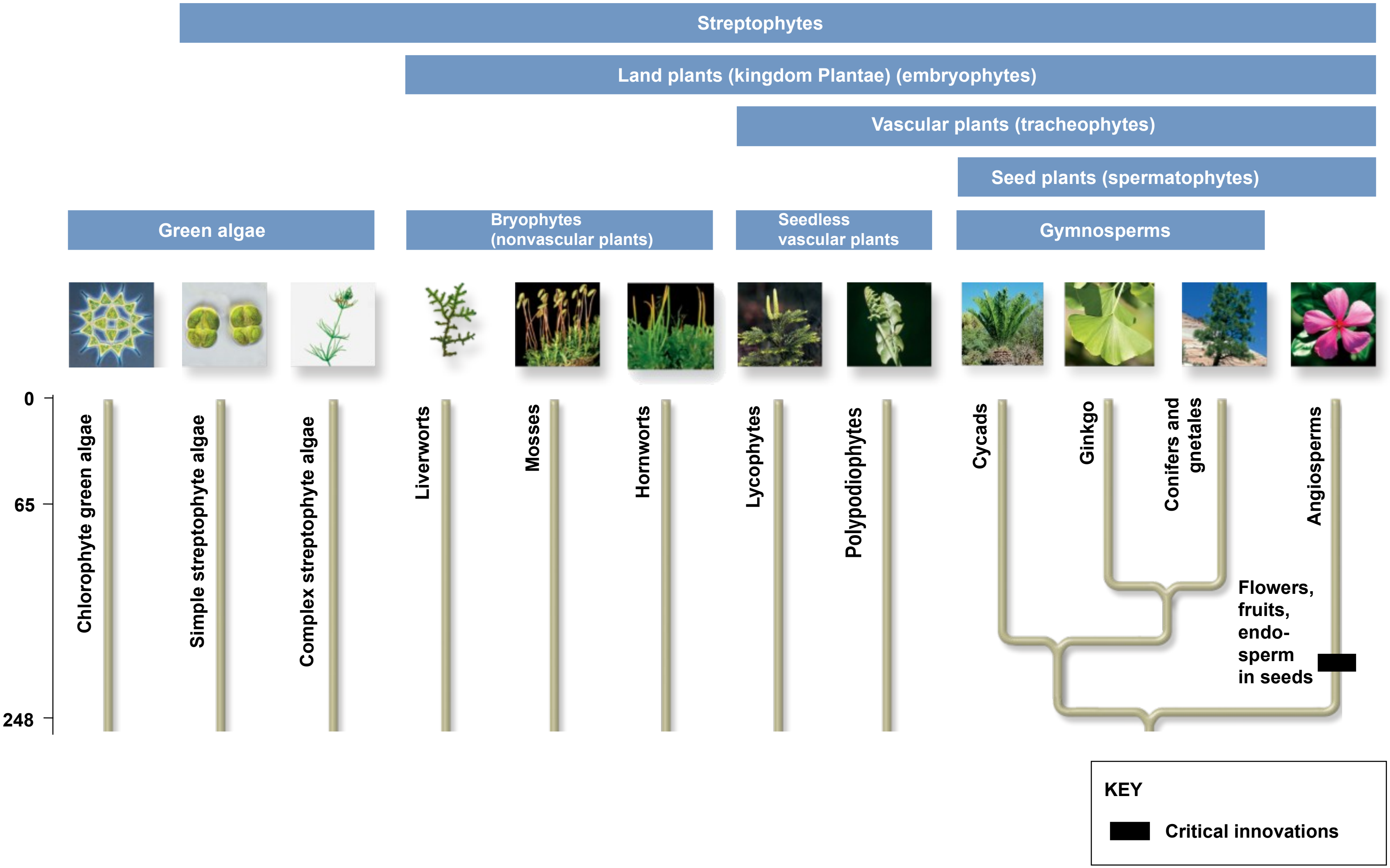

Streptophytes

Land plants (kingdom Plantae) (embryophytes)

Vascular plants (tracheophytes)

Seed plants (spermatophytes)

Green algae

Bryophytes (nonvascular plants)

Seedless vascular plants

Gymnosperms

0

65

248

Chlorophyte green algae

Simple streptophyte algae

Complex streptophyte algae

Liverworts

Mosses

Hornworts

Lycophytes

Polypodiophytes

Cycads

Ginkgo

Conifers and gnetales

Angiosperms

Flowers, fruits, endosperm in seeds

KEY

■ Critical innovations

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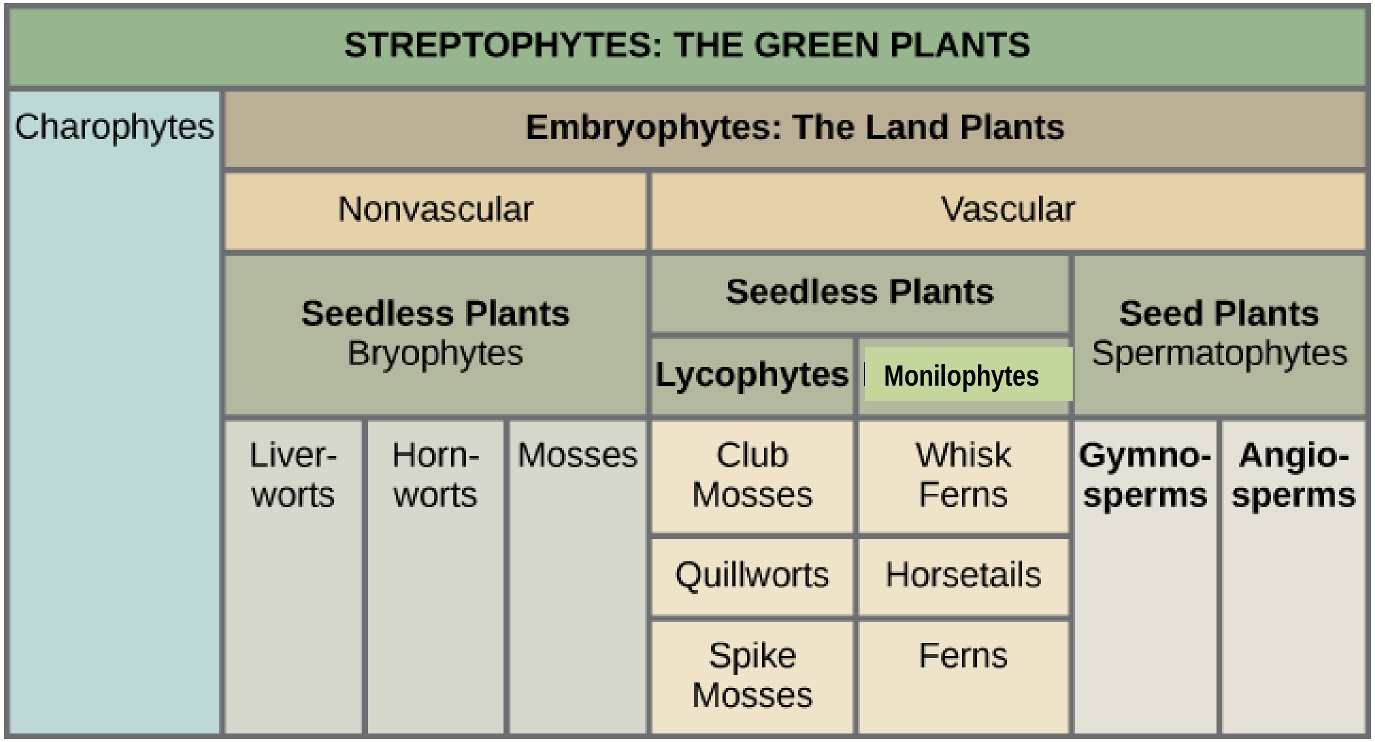
FIGURE 25.6



<table>
<tr><th colspan="8">STREPTOPHYTES: THE GREEN PLANTS</th></tr>
<tr><td rowspan="7">Charophytes</td><td colspan="7">Embryophytes: The Land Plants</td></tr>
<tr><td colspan="3">Nonvascular</td><td colspan="4">Vascular</td></tr>
<tr><td colspan="3" rowspan="2">Seedless Plants
Bryophytes</td><td colspan="2">Seedless Plants</td><td colspan="2" rowspan="2">Seed Plants
Spermatophytes</td></tr>
<tr><td>Lycophytes</td><td>Monilophytes</td></tr>
<tr><td rowspan="3">Liverworts</td><td rowspan="3">Hornworts</td><td rowspan="3">Mosses</td><td>Club Mosses</td><td>Whisk Ferns</td><td rowspan="3">Gymnosperms</td><td rowspan="3">Angiosperms</td></tr>
<tr><td>Quillworts</td><td>Horsetails</td></tr>
<tr><td>Spike Mosses</td><td>Ferns</td></tr>
</table>

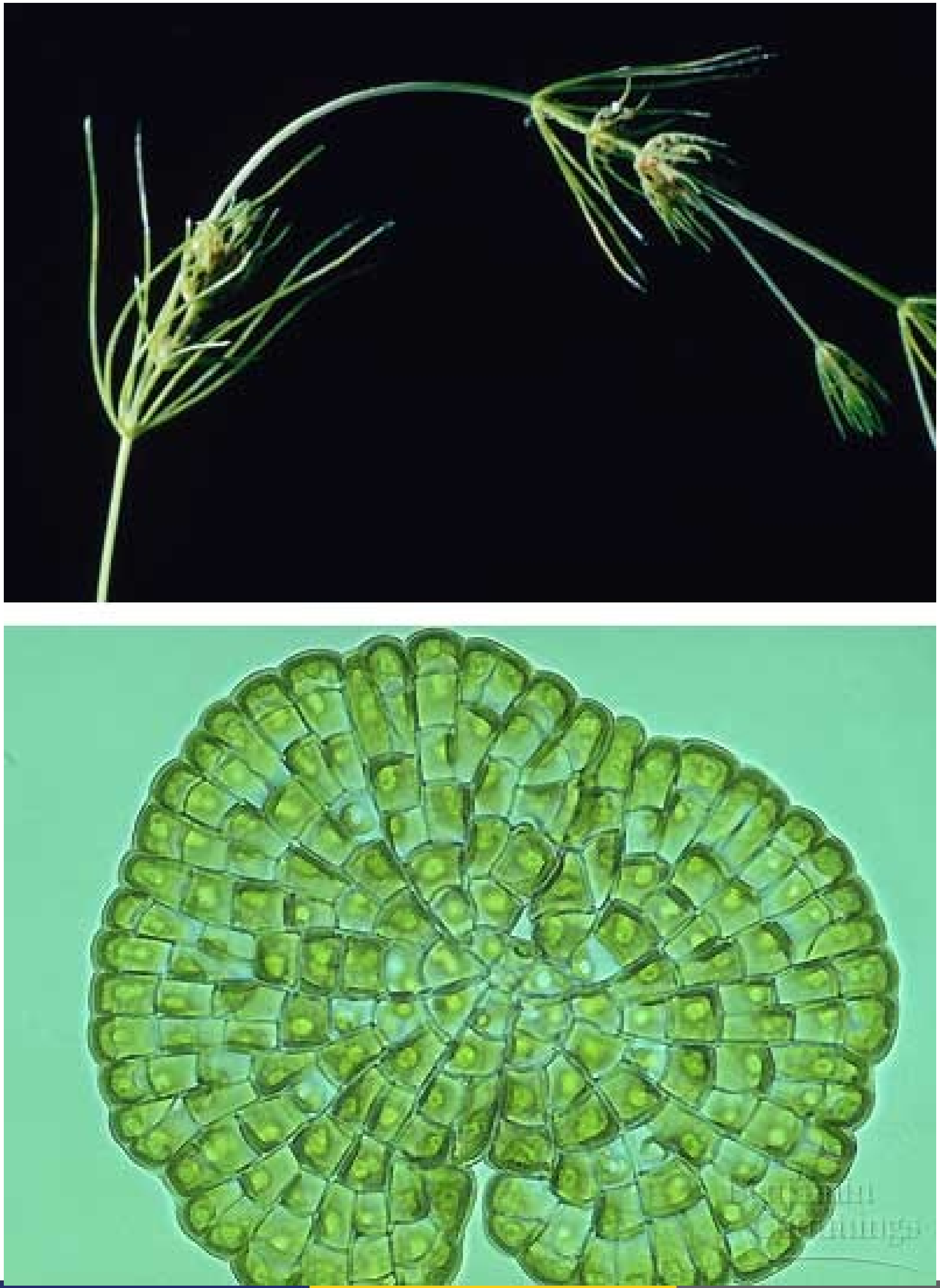
(Zygnematophyceae)

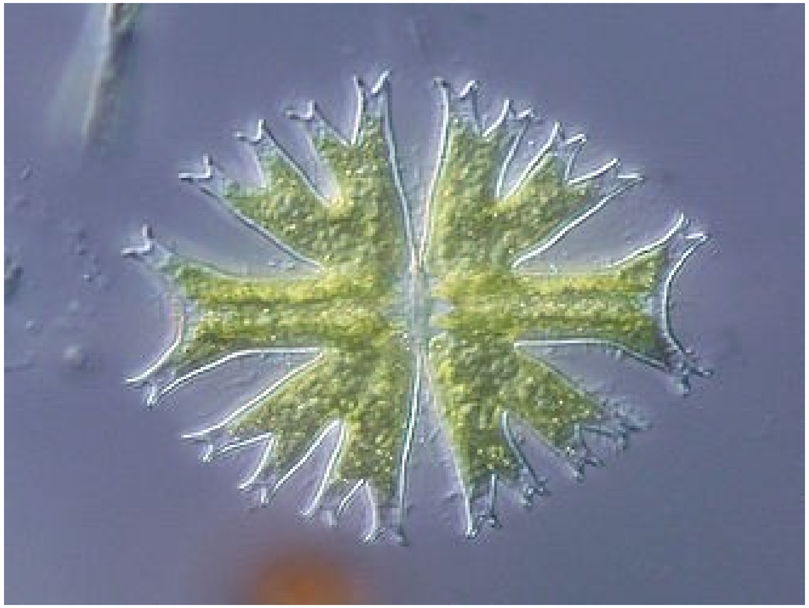
This table shows the major divisions of green plants.

ANCESTRY

- Probably originated from a photosynthetic **protist ancestor** with a relatively complex body
  - Filament of cells with side branches
- Either ***Chara*** or ***Coleochaete*** were once thought to be the modern protist algaes most closely related to the ancestor of land plants (both are Charophytes)
- Ancestor now believed to be Zygnematophyceae, a Charophyte single celled algae that shares DNA with modern land plants and with certain bacteria (preventing desiccation)

CHAROPHYCEANS: *CHARA* (TOP), *COLEOCHAETE ORBICULARIS* (BOTTOM)





A Desmid from the Zygnematophyceae: Shares DNA with land plants

Charophyceans share several **derived** traits with land plants

- Distinctive type of cytokinesis (cell division) with cell plate
- Sexual reproduction using egg and smaller sperm
- Chlorophyll a and b and carotene as pigments (remember photosynthetic bacteria endosymbiosis?)
- Cellulose cell wall
- Starch as C storage molecule
- RNA and DNA sequences
- Rhizoids to hold to surface

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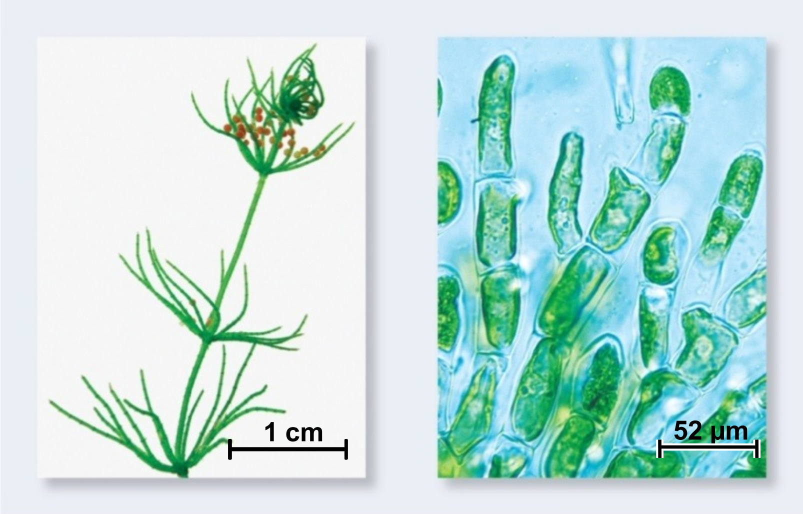
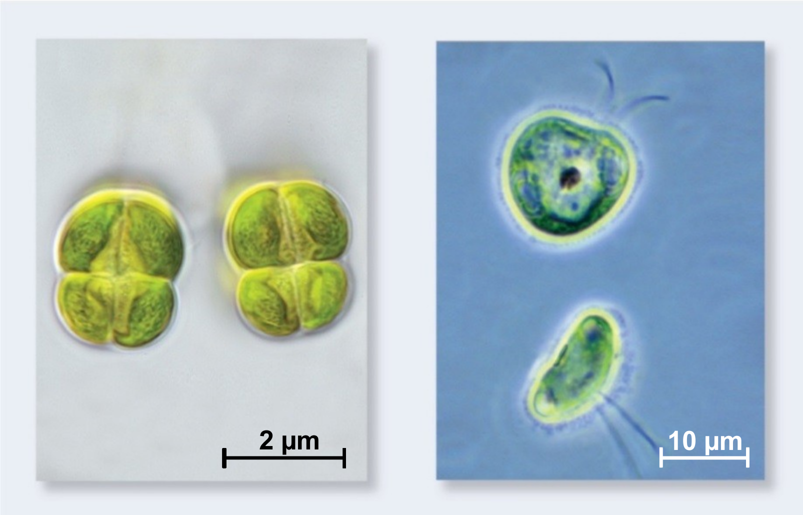


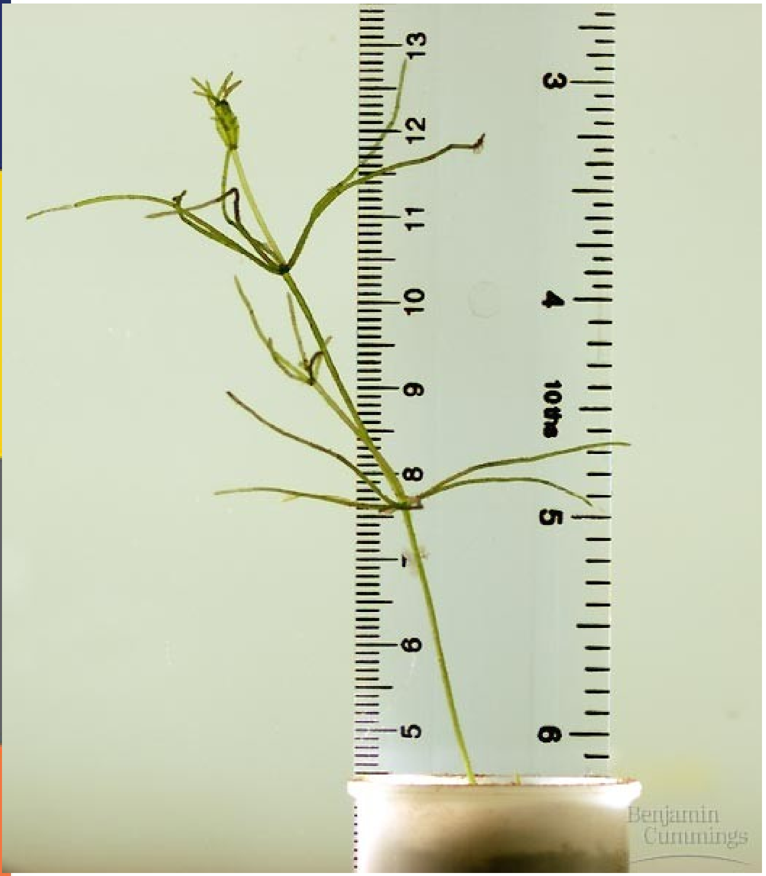
(a) Complex streptophyte algae: ***Chara zeylanica*** **(left) and** ***Coleochaete pulvinata*** **(right)**



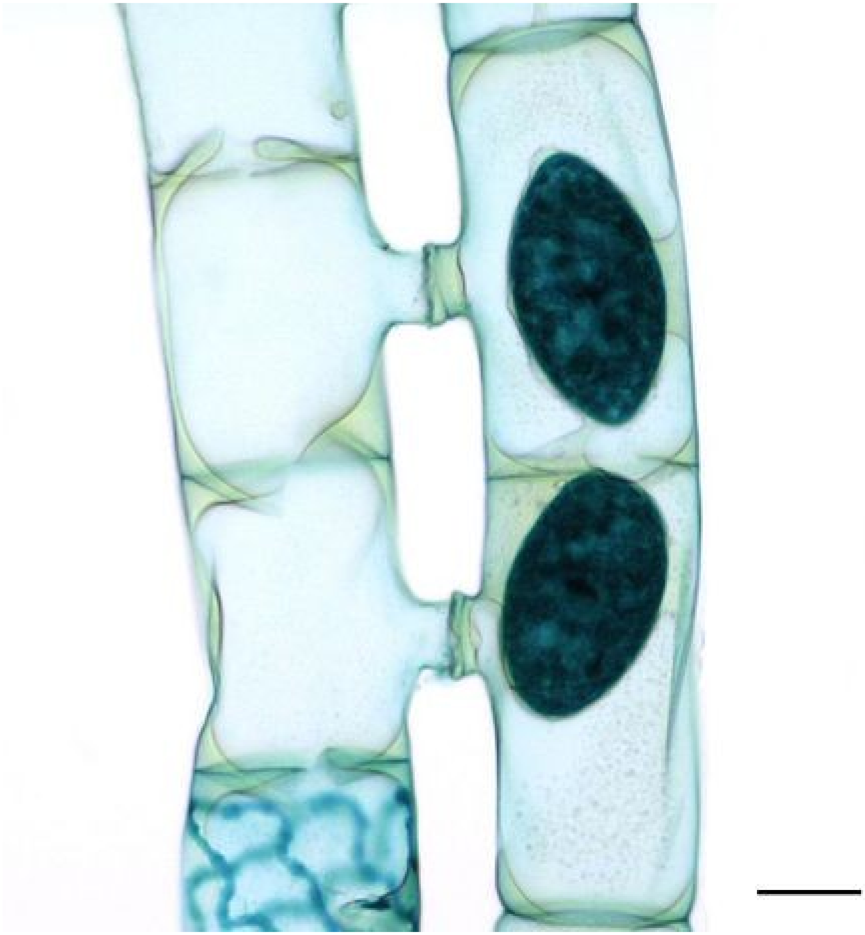
(b) Simple streptophyte algae: ***Chlorokybus atmophyticus*** **(left) and** ***Mesostigma viridae*** **(right)**

a (left): © Lee W. Wilcox; a (right): © Linda Graham; b (left): © the CAUP image database, http://botany.natur.cuni.cz/algo/database; b (right): © Lee W. Wilcox

CHARA



SPYROGYRA CONJUGATING



WHAT MAKES TERRESTRIAL PLANTS DIFFERENT FROM ALGAE: WHAT ARE THE DERIVED CHARACTERS?

- **APICAL MERISTEMS**
- **MULTICELLULAR DEPENDENT EMBRYOS**
- **ALTERNATION OF GENERATIONS**
- **WALLED SPORES PRODUCED IN SPORANGIA**
- **MULTICELLULAR GAMETANGIA**
- **WAXY CUTICLES AND STOMATA**
- **VASCULAR TISSUE**

APICAL MERISTEMS OF PLANT SHOOTS AND ROOTS

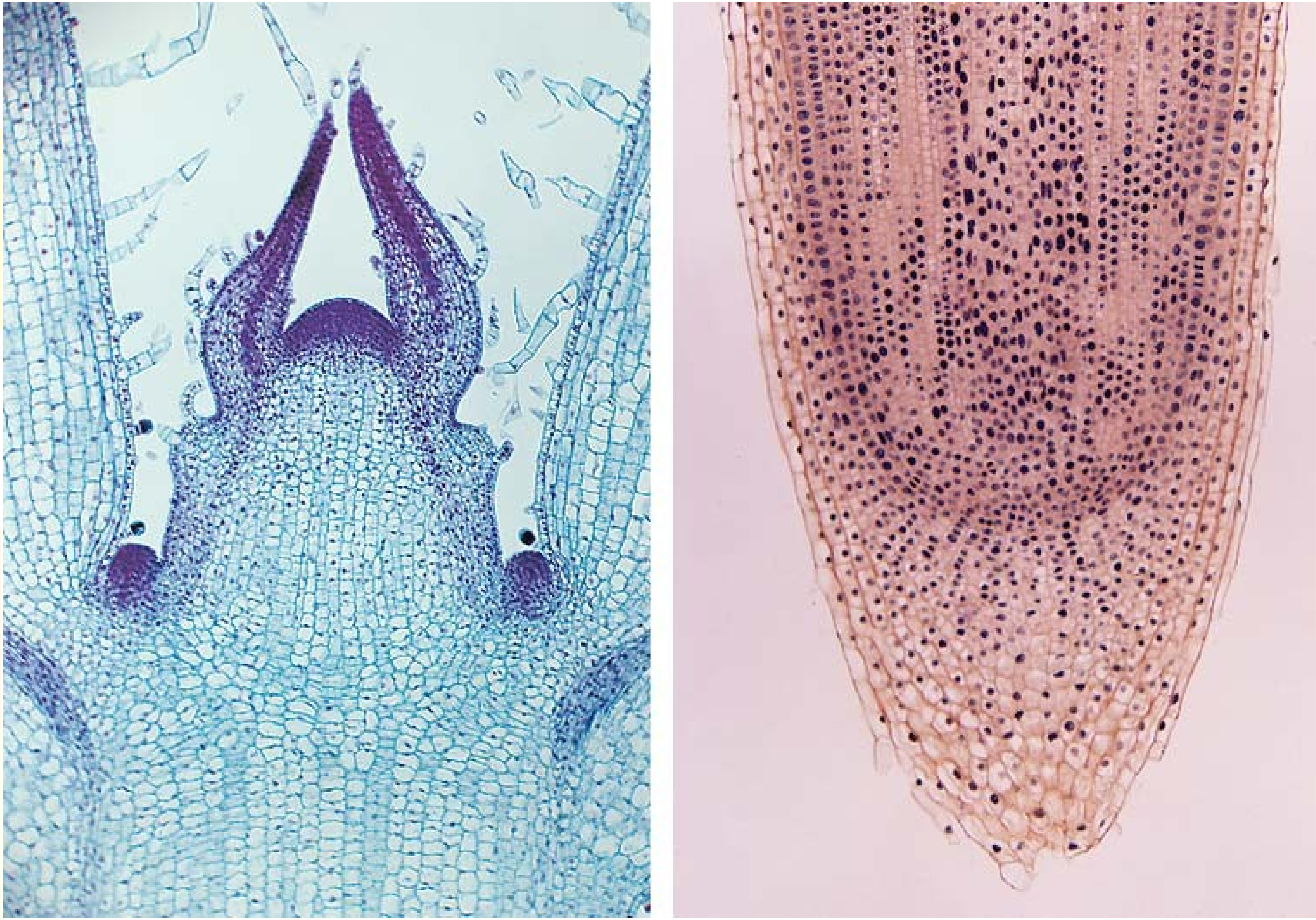
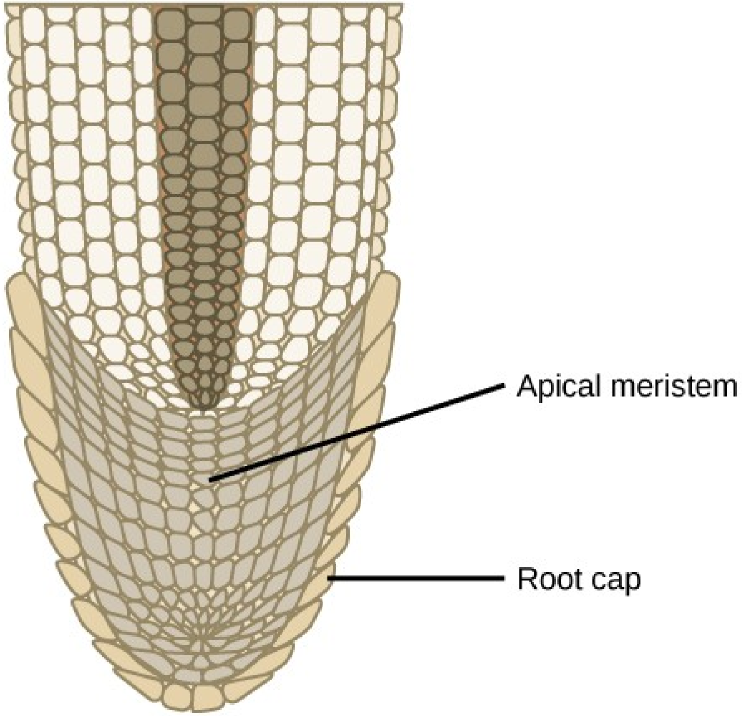


FIGURE 25.4



Addition of new cells in a root occurs at the apical meristem. Subsequent enlargement of these cells causes the organ to grow and elongate. The root cap protects the fragile apical meristem as the root tip is pushed through the soil by cell elongation.

SPOROPHYTE OF *MARCHANTIA*, A LIVERWORT

Multicellular
dependent
embryo

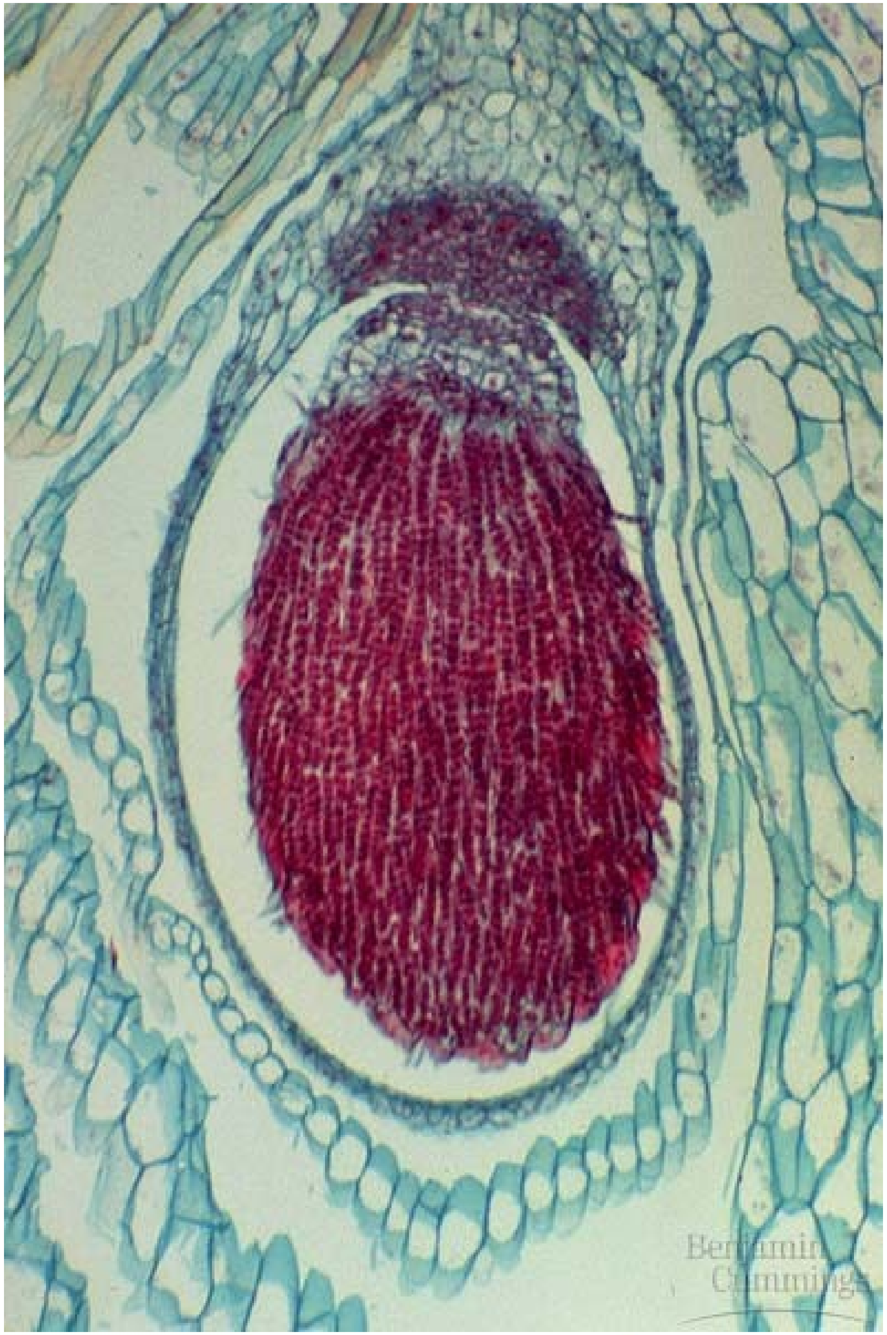

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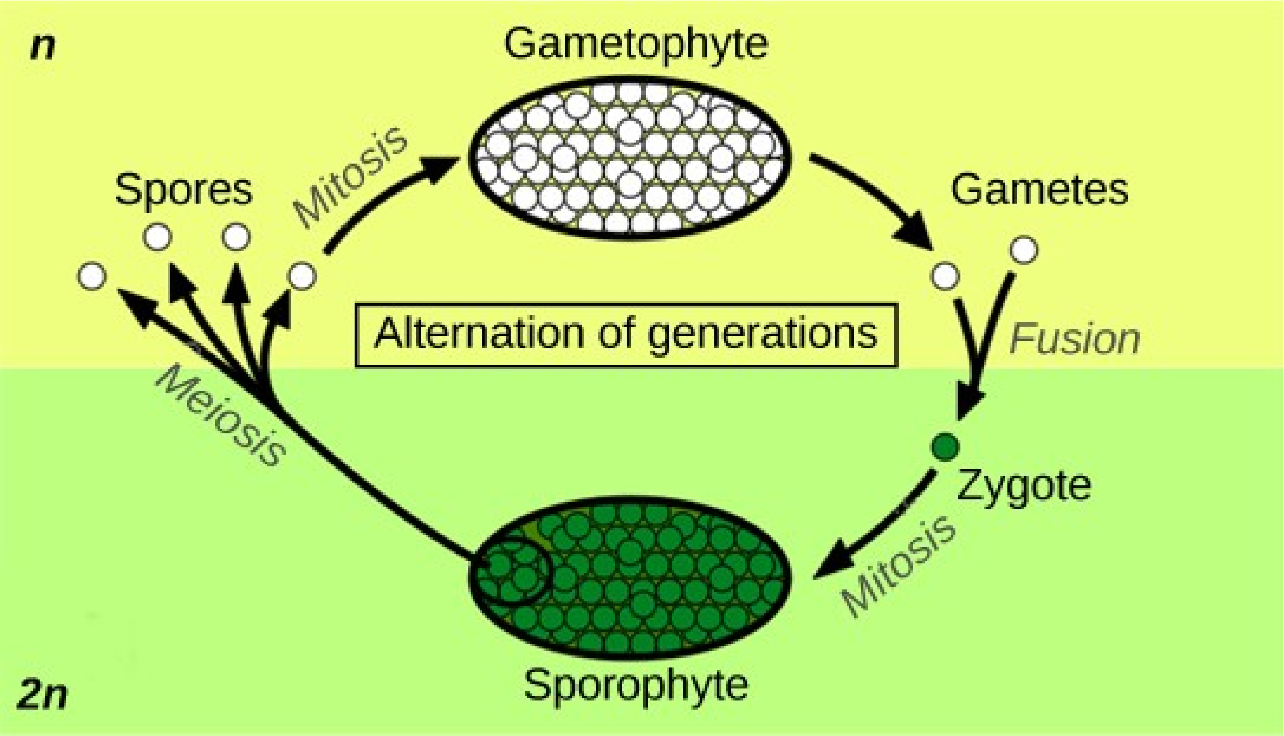
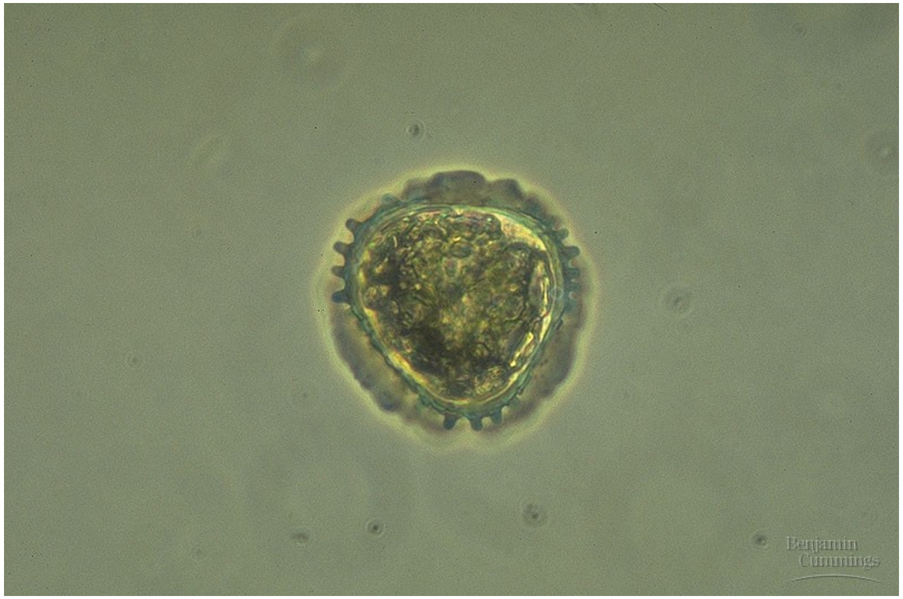
FIGURE 25.2 ALTERNATION OF GENERATIONS

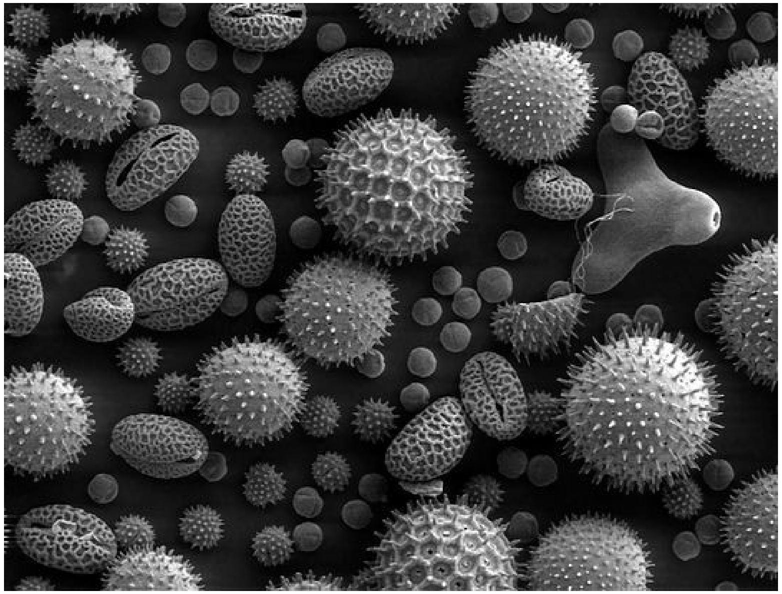


Alternation of generations between the 1*n* gametophyte and 2*n* sporophyte is shown. (credit: Peter Coxhead)

WALLED SPORES

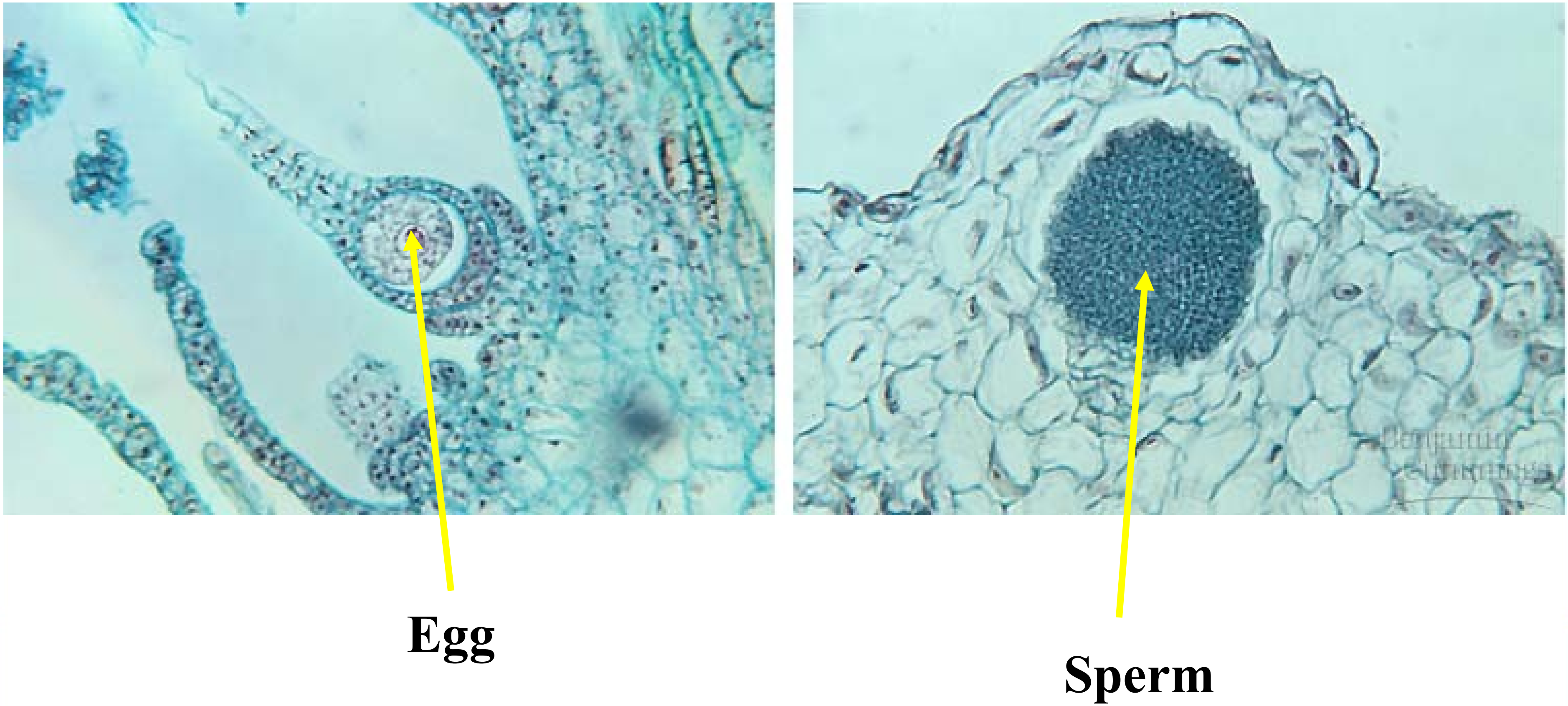
A FERN SPORE **POLLEN GRAINS**



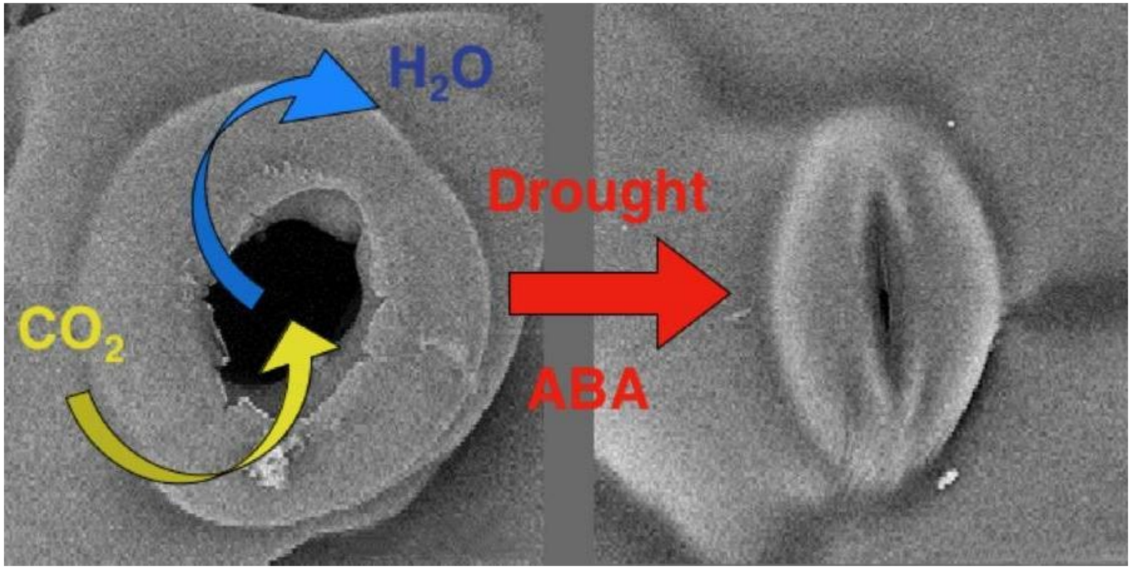


Sporopollenin, one of the most chemically inert biological polymers, is highly resistant to physical, chemical and biological degradation procedures. Tough outer covering of spores and pollen.
Chemically cross linked biopolymers including long chain fatty acids, phenolics, phenylpropanoids, and some carotenoids.

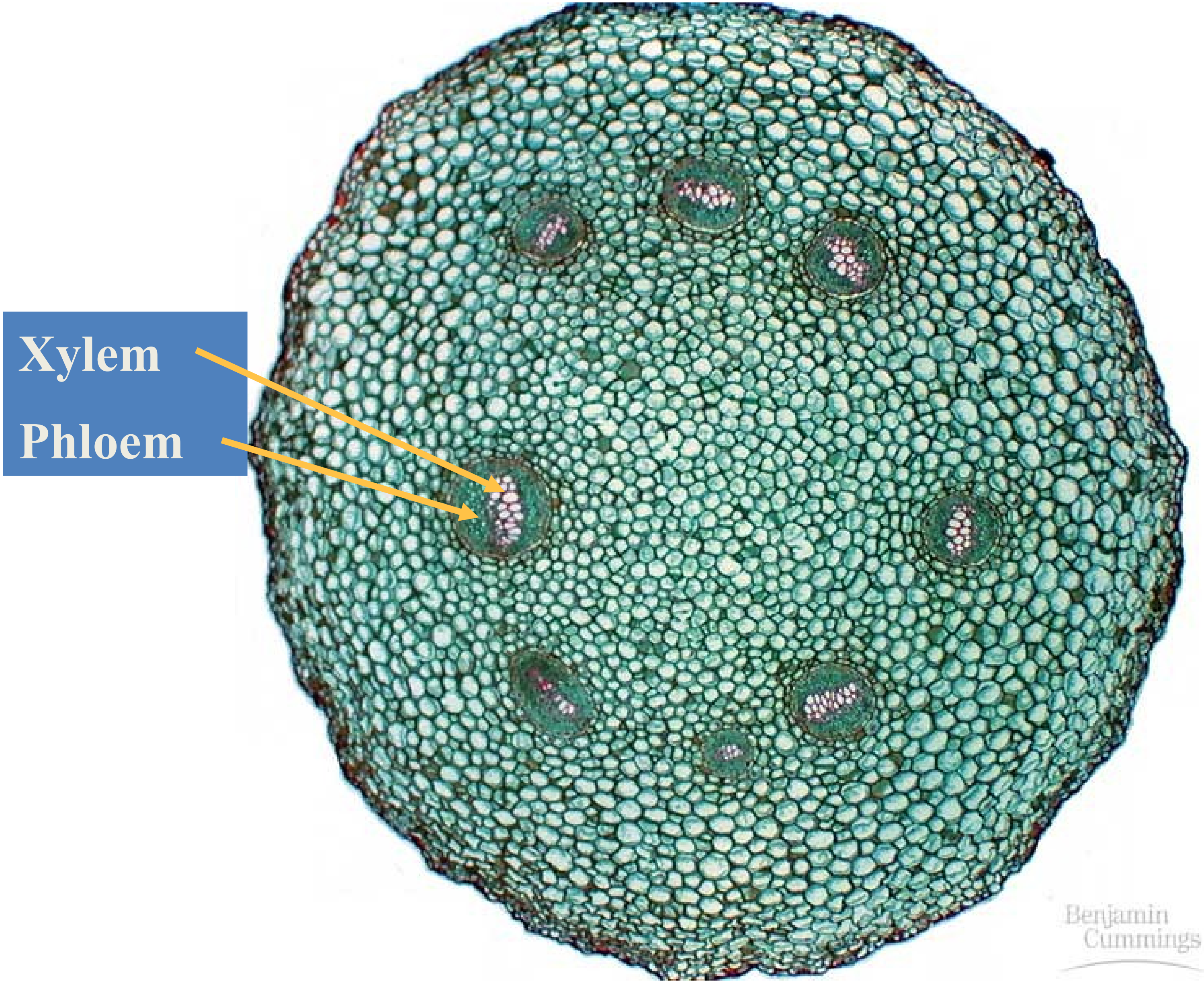
MULTICELLULAR GAMETANGIA: ARCHEGONIUM OF *MARCHANTIA*, A LIVERWORT (LEFT), ANTHERIDIUM OF A HORNWORT (RIGHT)



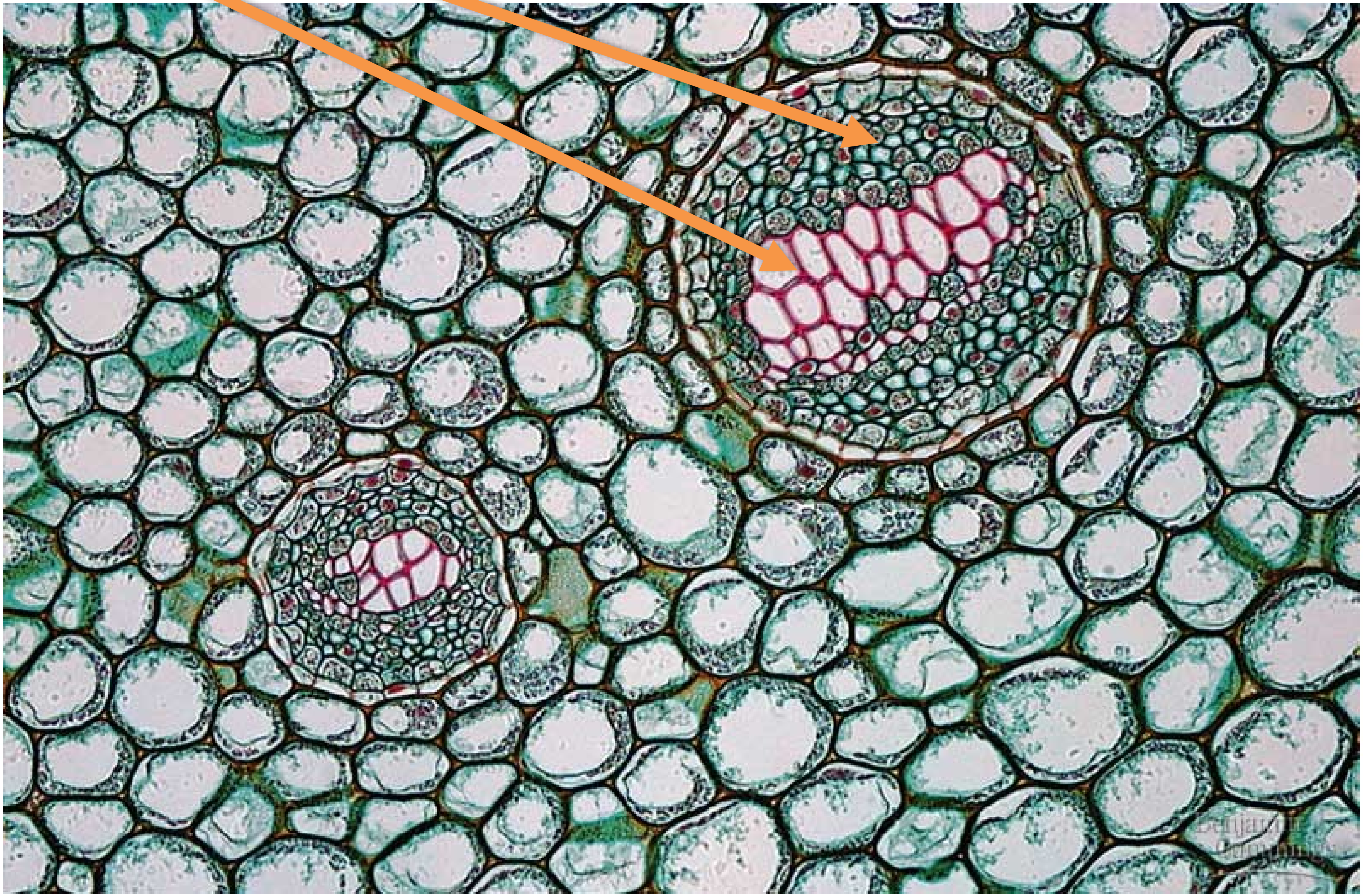
WAXY CUTICLES AND STOMATA



THE STEM OF *POLYPODIUM*, A FERN (A POLYPODIOPHYTE) VASCULAR TISSUE



XYLEM AND PHLOEM IN THE STEM OF *POLYPODIUM*, A FERN (A POLYPODIOPHYTE)



TEN PLANT PHYLA (THE OLDER BOTANICAL TERM FOR PHYLUM IS DIVISION)

NON-VASCULAR PLANTS

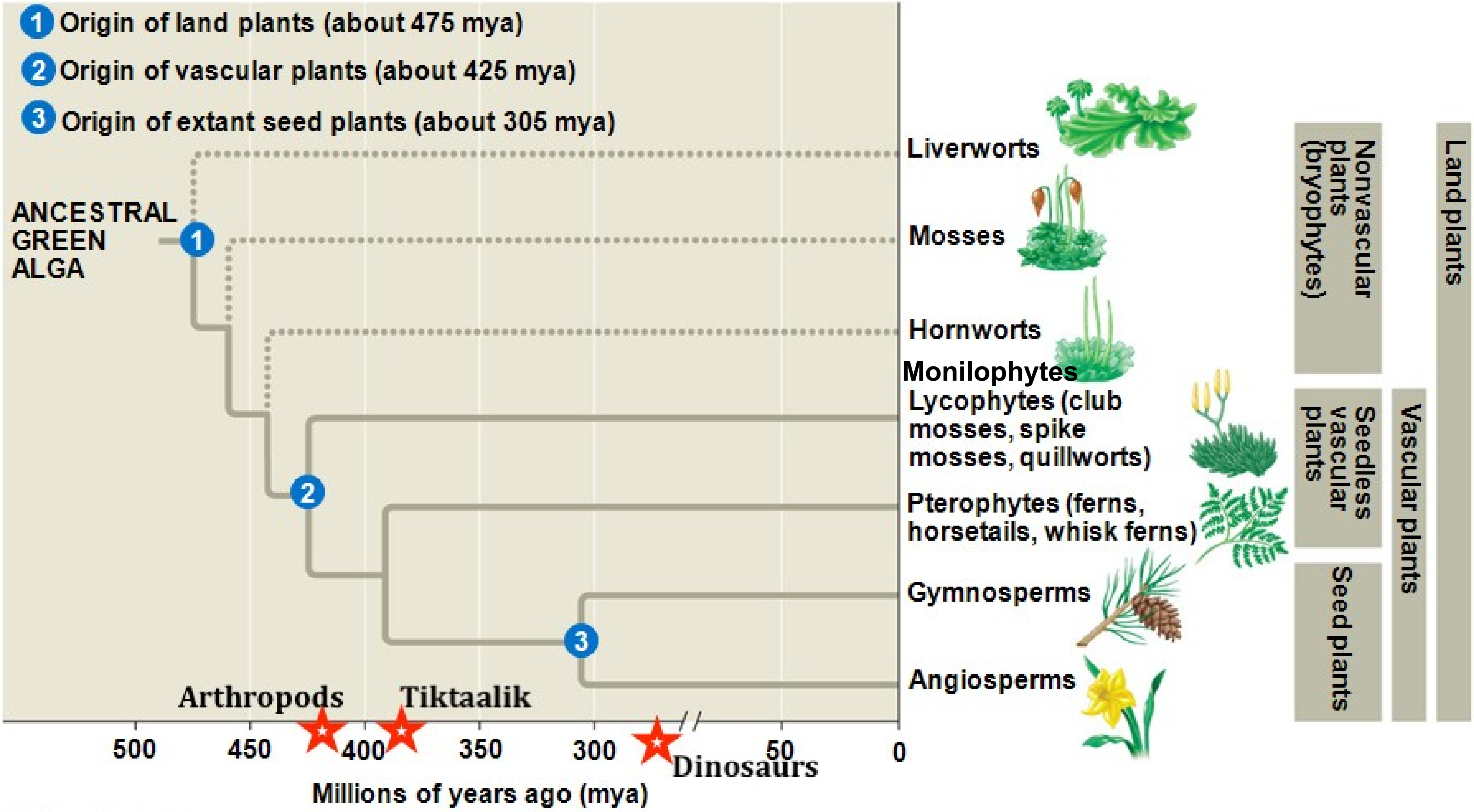
1. **Liverworts** – Hepatophyta
2. **Mosses** – Bryophyta
3. **Hornworts** – Anthocerophyta

Bryophytes used as a **common** term for these three Phyla

VASCULAR PLANTS

4. **Lycophytes** – Lycophyta (club moss)
5. **Monilophytes** – Monilophytes (ferns, whisk ferns, horsetails)
6. **Cycads** – Cycadophyta
7. **Welwitschia, Ephedra** – Gnetophyta
8. **Ginkgos** – Ginkgophyta
9. **Conifers** – Coniferophyta
10. **Angiosperms** – Anthophyta (flowering plants)

SEED PLANTS


1 Origin of land plants (about 475 mya)
2 Origin of vascular plants (about 425 mya)
3 Origin of extant seed plants (about 305 mya)
ANCESTRAL GREEN ALGA
1
2
3
Liverworts
Mosses
Hornworts
Monilophytes
Lycophytes (club mosses, spike mosses, quillworts)
Pterophytes (ferns, horsetails, whisk ferns)
Gymnosperms
Angiosperms
Nonvascular plants (bryophytes)
Seedless vascular plants
Seed plants
Vascular plants
Land plants
Arthropods
Tiktaalik
Dinosaurs
500
450
400
350
300
50
0
Millions of years ago (mya)

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BRYOPHYTES - GENERAL

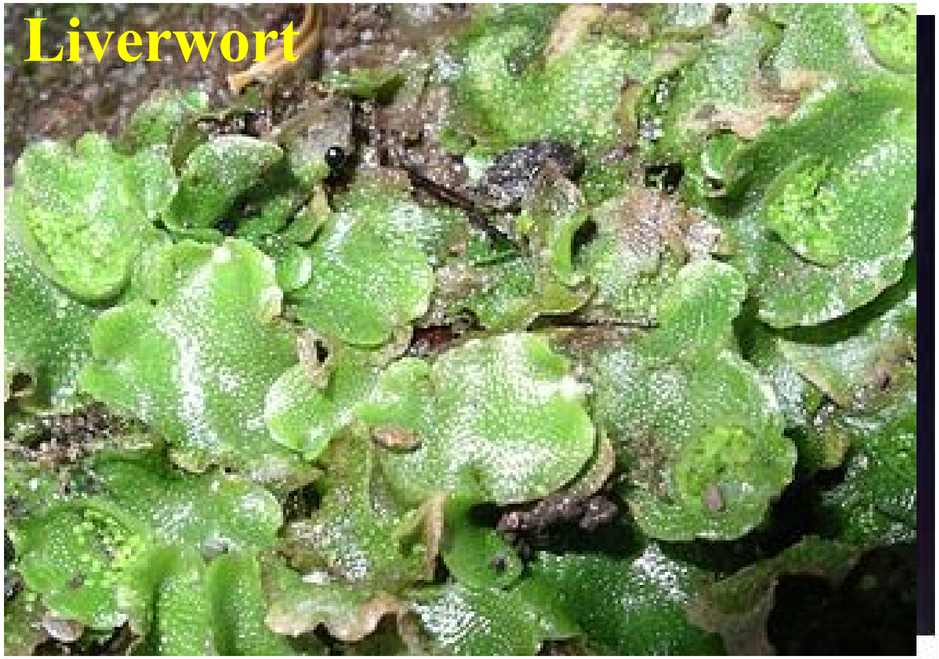
Include **liverworts, hornworts,** and **mosses**

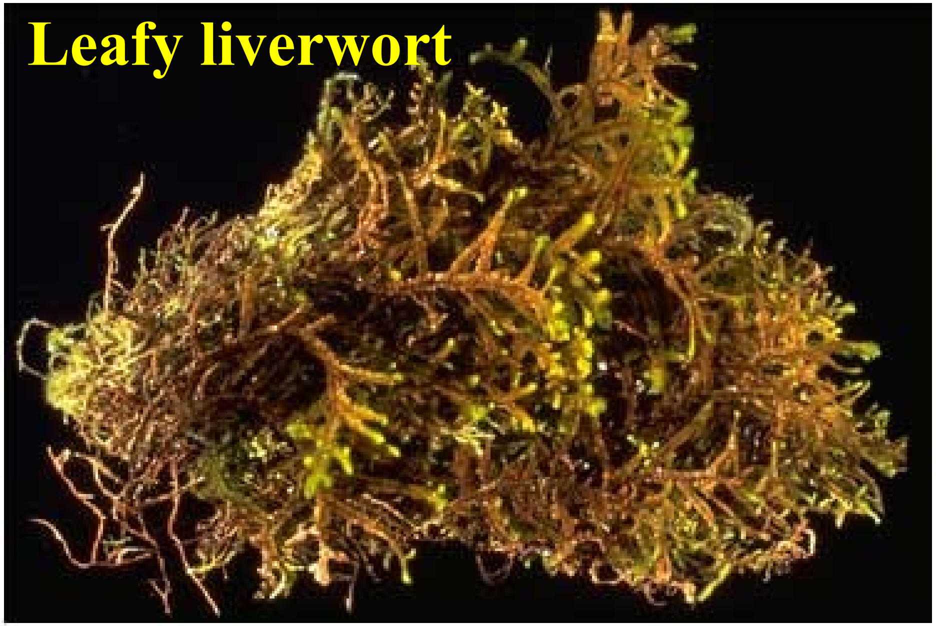
Each forms a monophyletic phylum

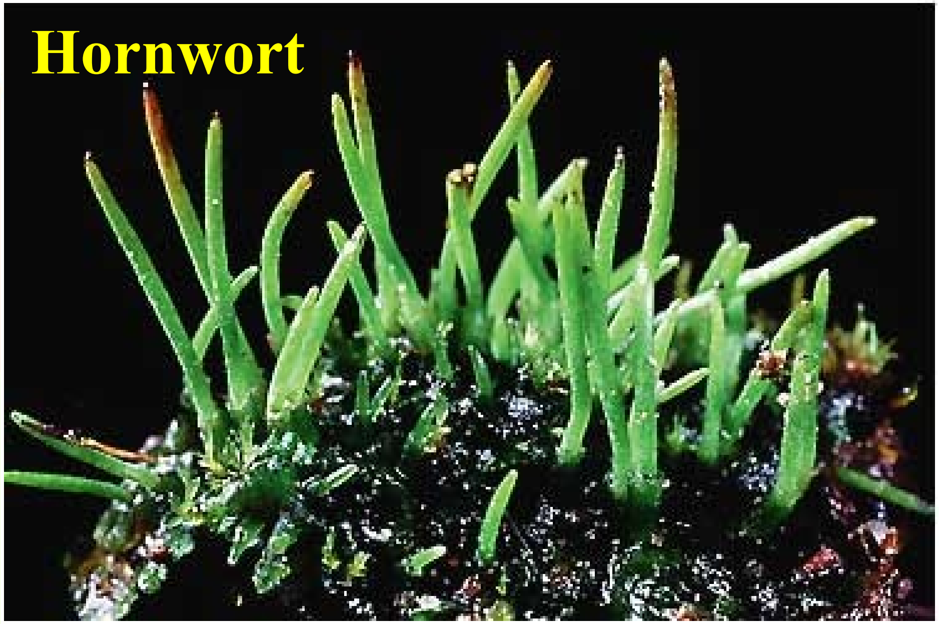
Share common structural, reproductive and ecological features

Dependent on presence of water for sexual reproduction

BRYOPHYTES


Liverwort


Leafy liverwort


Hornwort

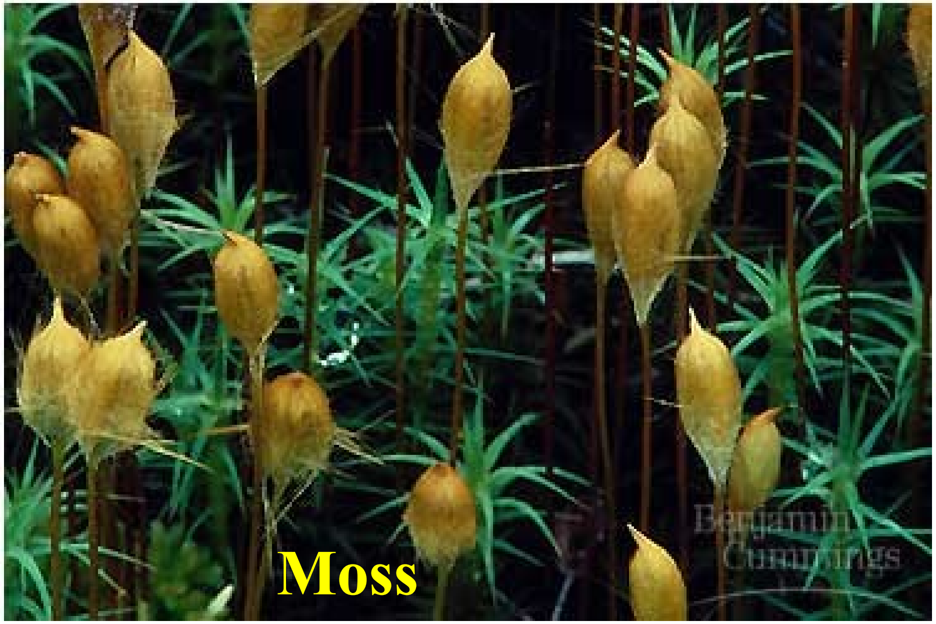
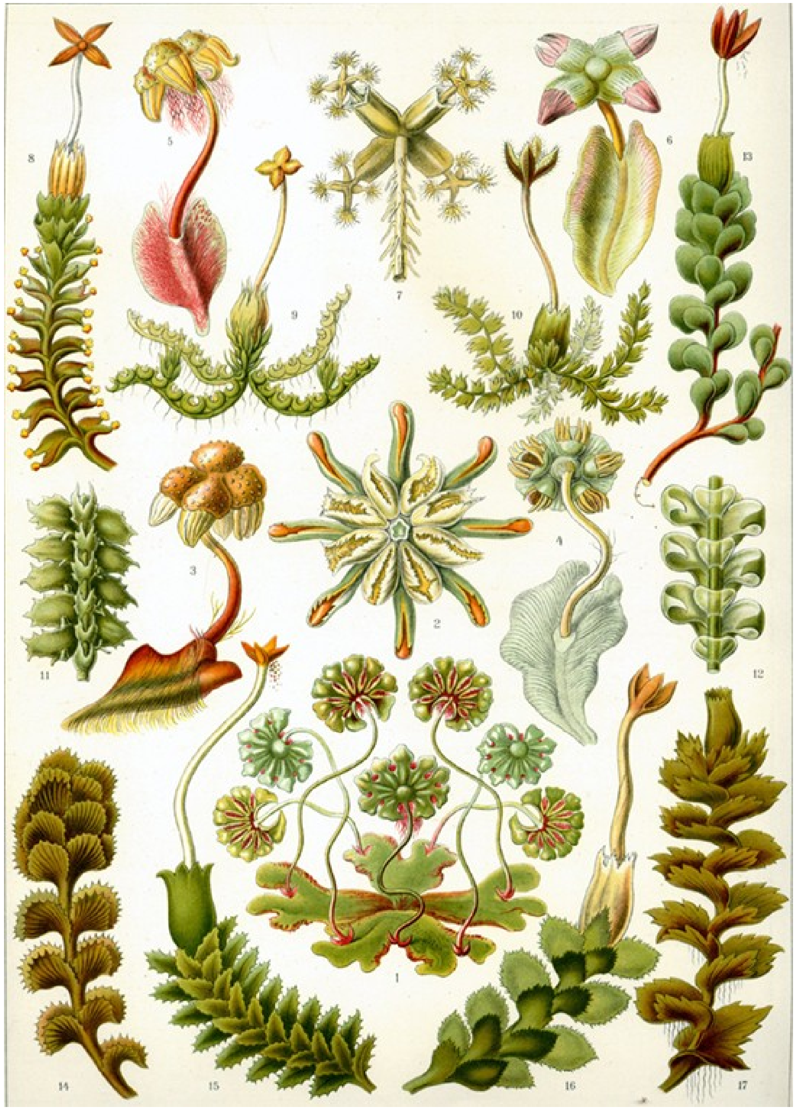
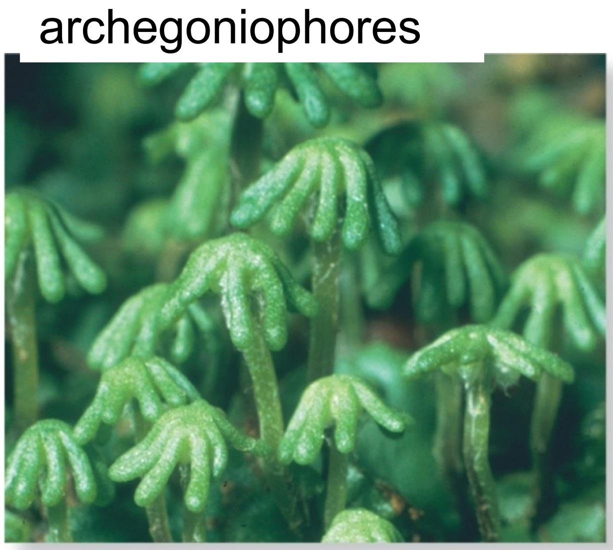

Moss

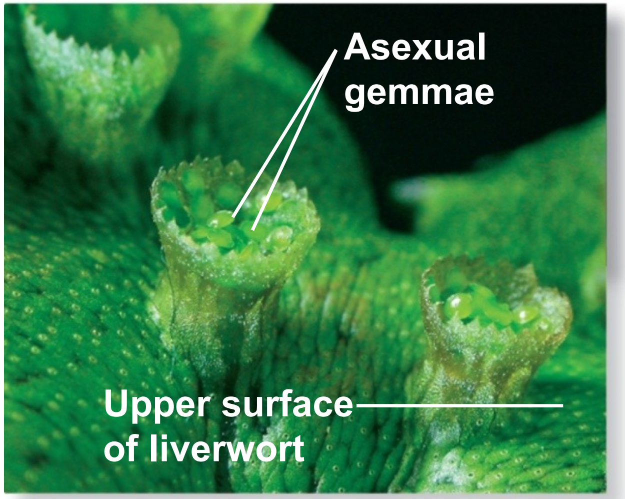
FIGURE 25.9



This 1904 drawing shows the variety of forms of Hepaticophyta.



(a) The common liverwort, *Marchantia polymorpha*



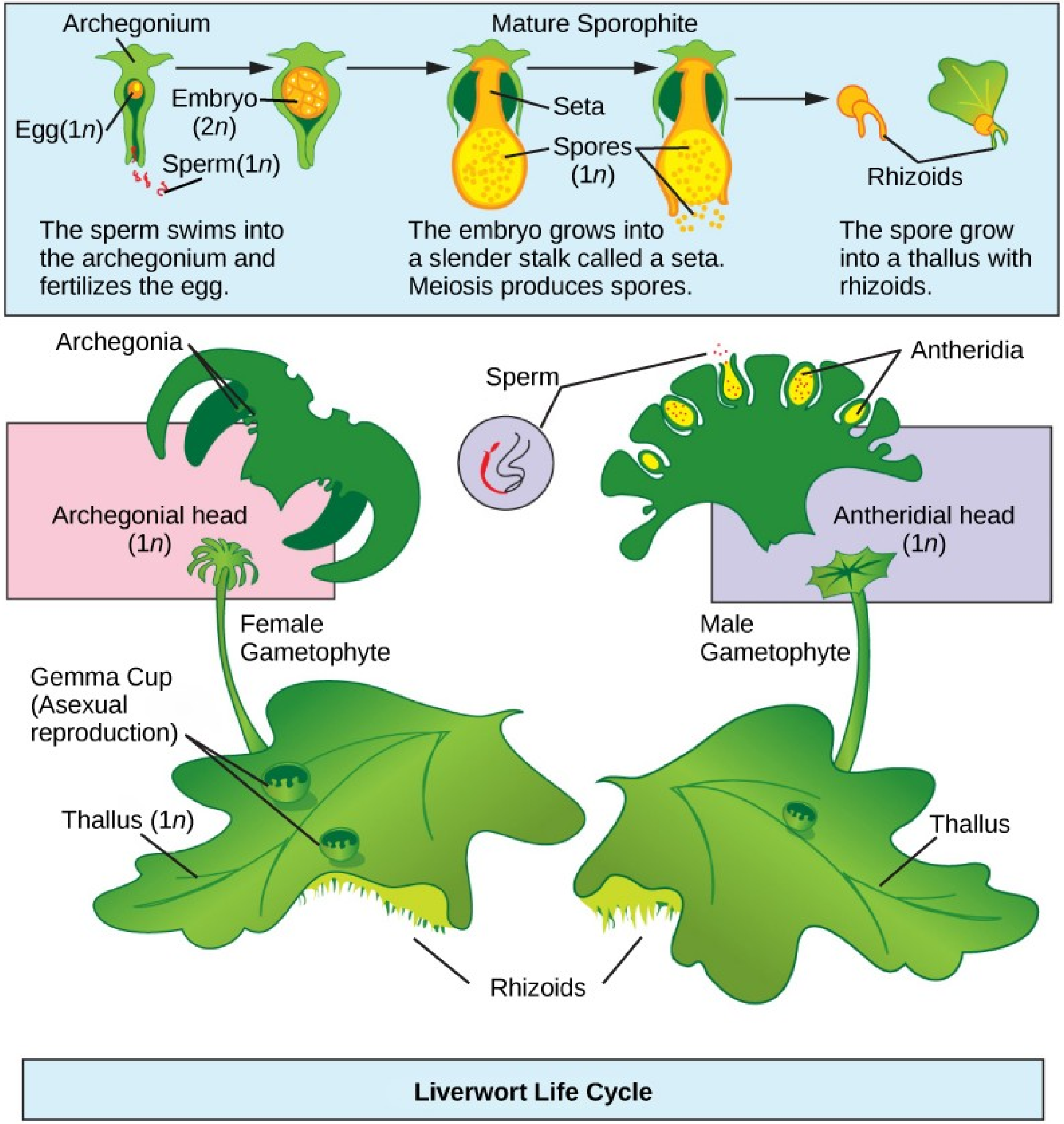
(b) Close-up of liverwort structures

(c) A species of leafy liverwort

a: © Dr. Jeremy Burgess/SPL/Photo Researchers, Inc.; b: © Lee W. Wilcox

HEPATOPHYTA – LIVERWORT FIGURE 25.11

The life cycle of a typical liverwort is shown. (credit: modification of work by Mariana Ruiz Villareal)



The sperm swims into the archegonium and fertilizes the egg.

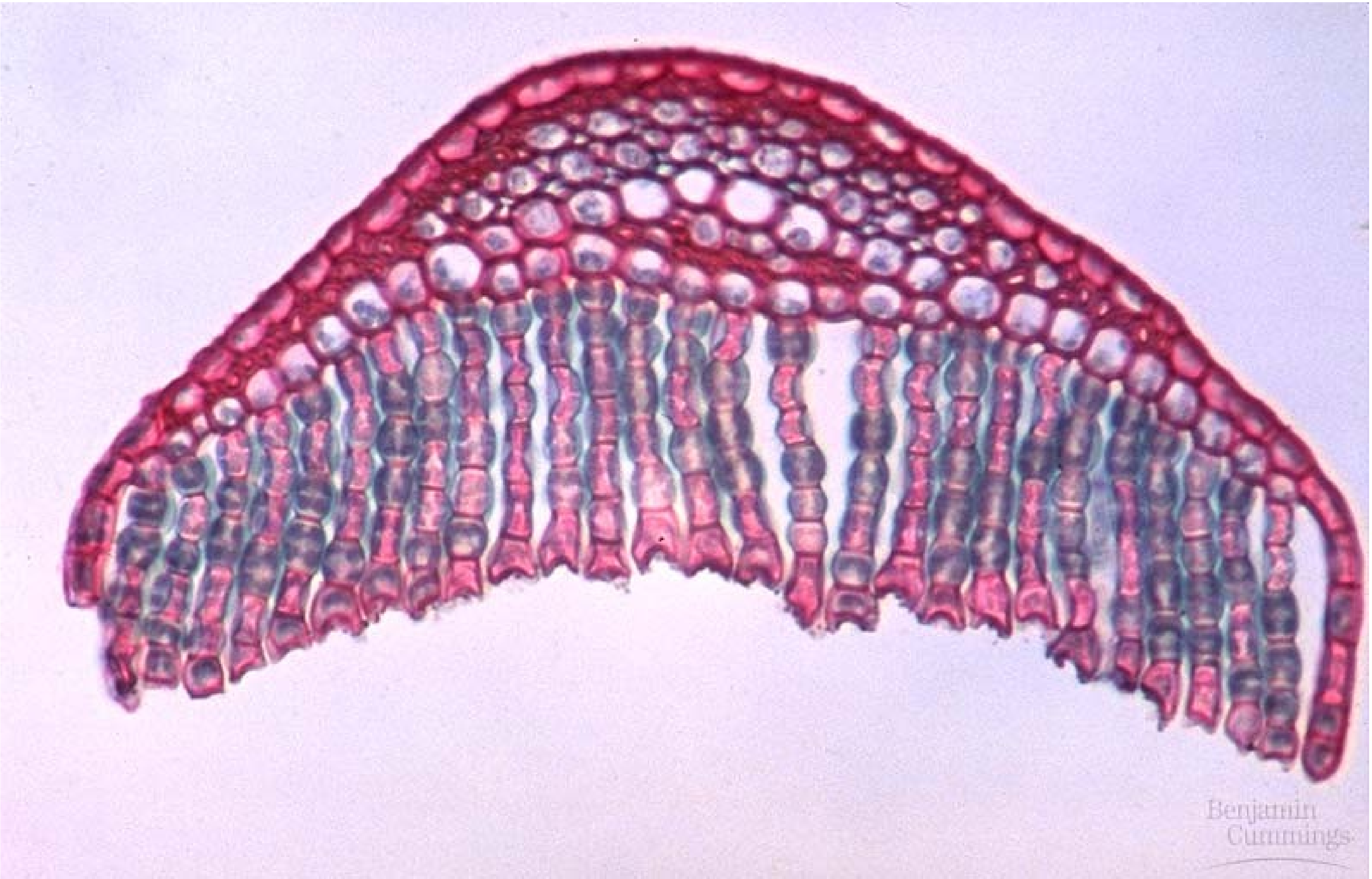
The embryo grows into a slender stalk called a seta. Meiosis produces spores.

The spore grow into a thallus with rhizoids.

Liverwort Life Cycle

MOSSES - BRYOPHYTA

POLYTRICHUM MOSS LEAF SECTION



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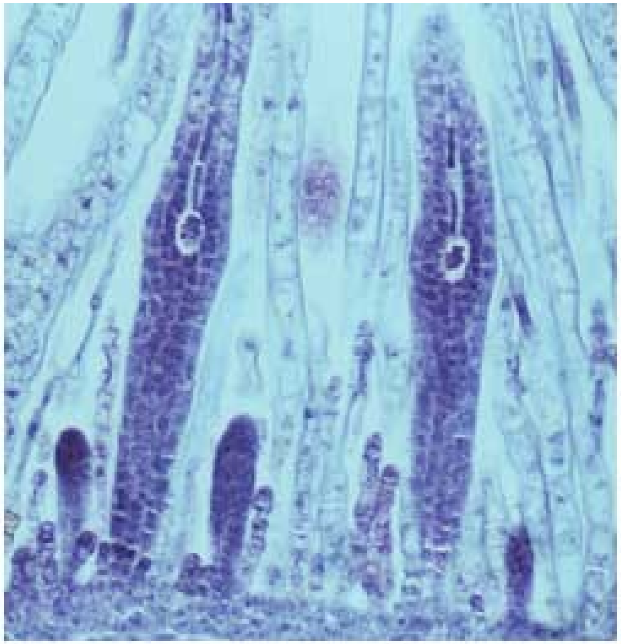
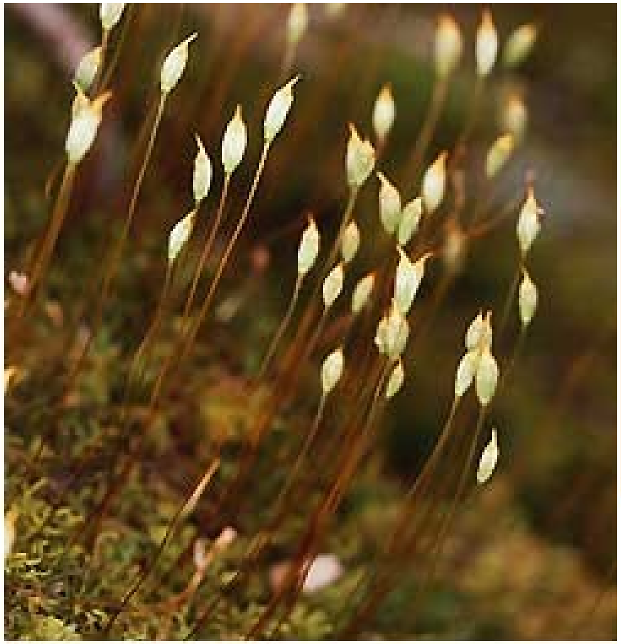
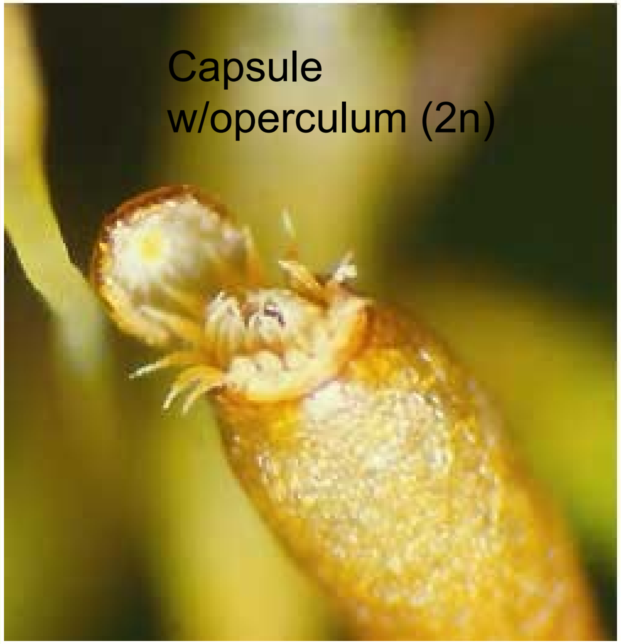
MOSS LIFE CYCLE

Archegonia

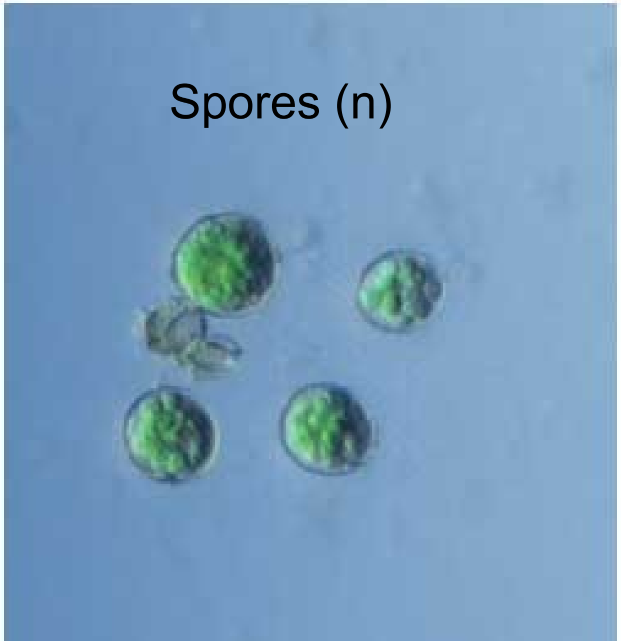


Sporophyte (2n)

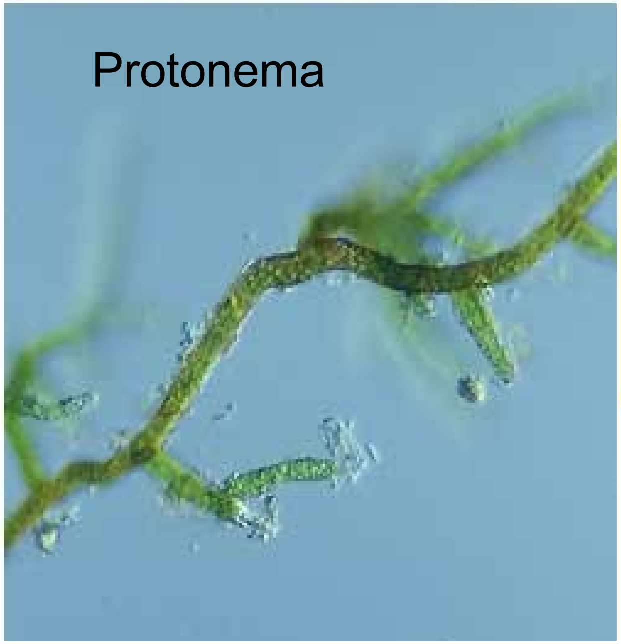




Capsule
w/operculum (2n)

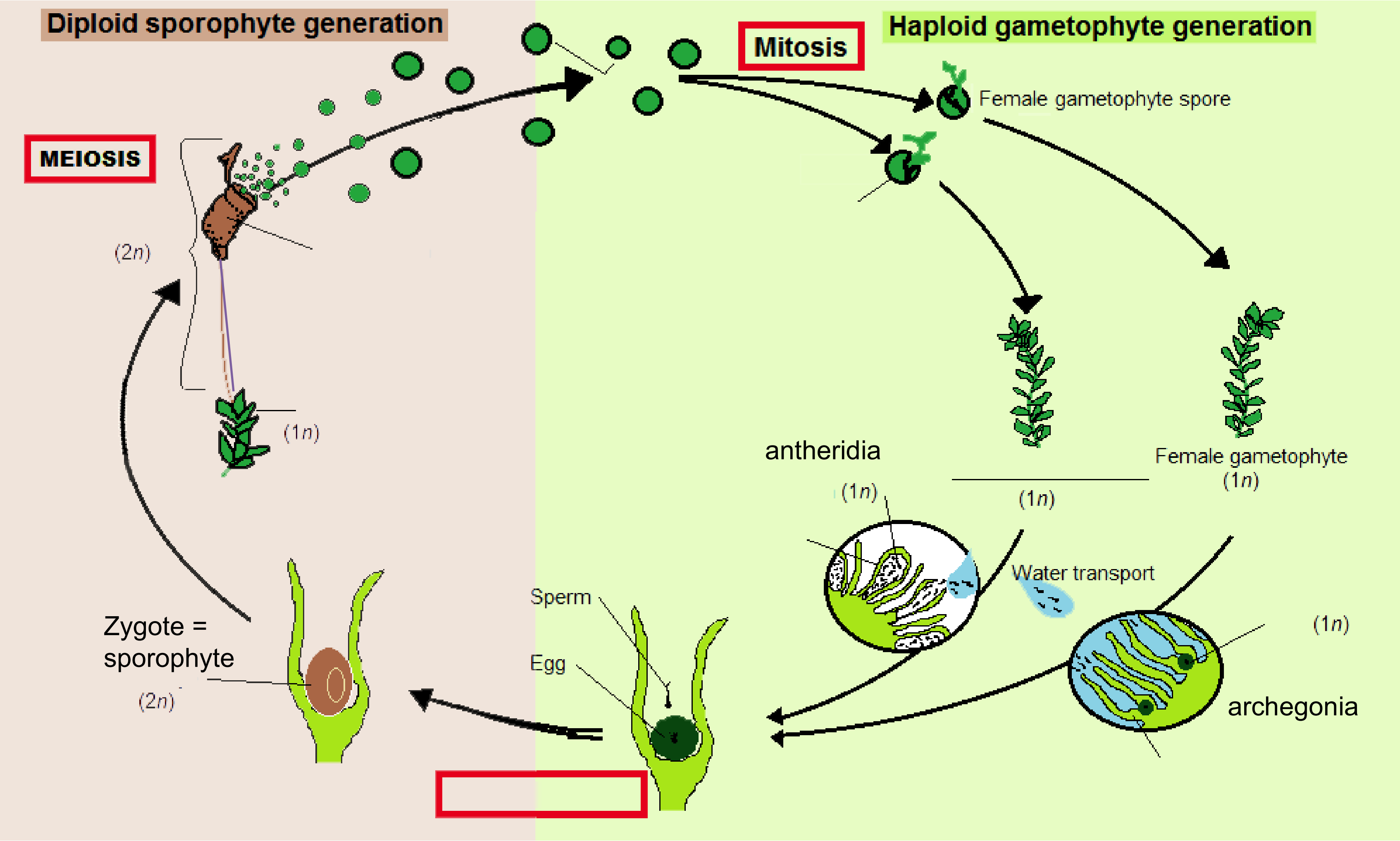


Spores (n)



Protonema

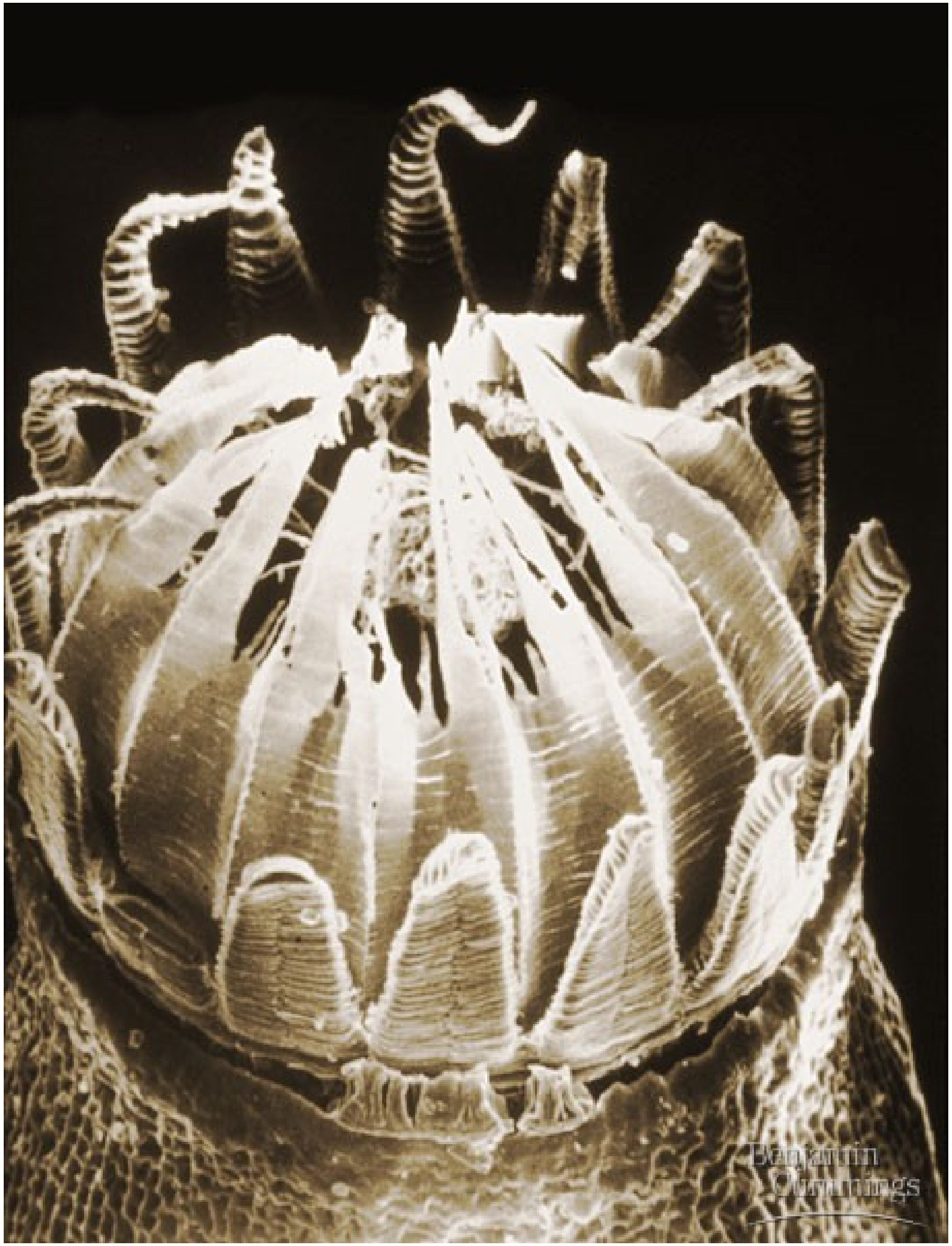
MOSS LIFE CYCLE



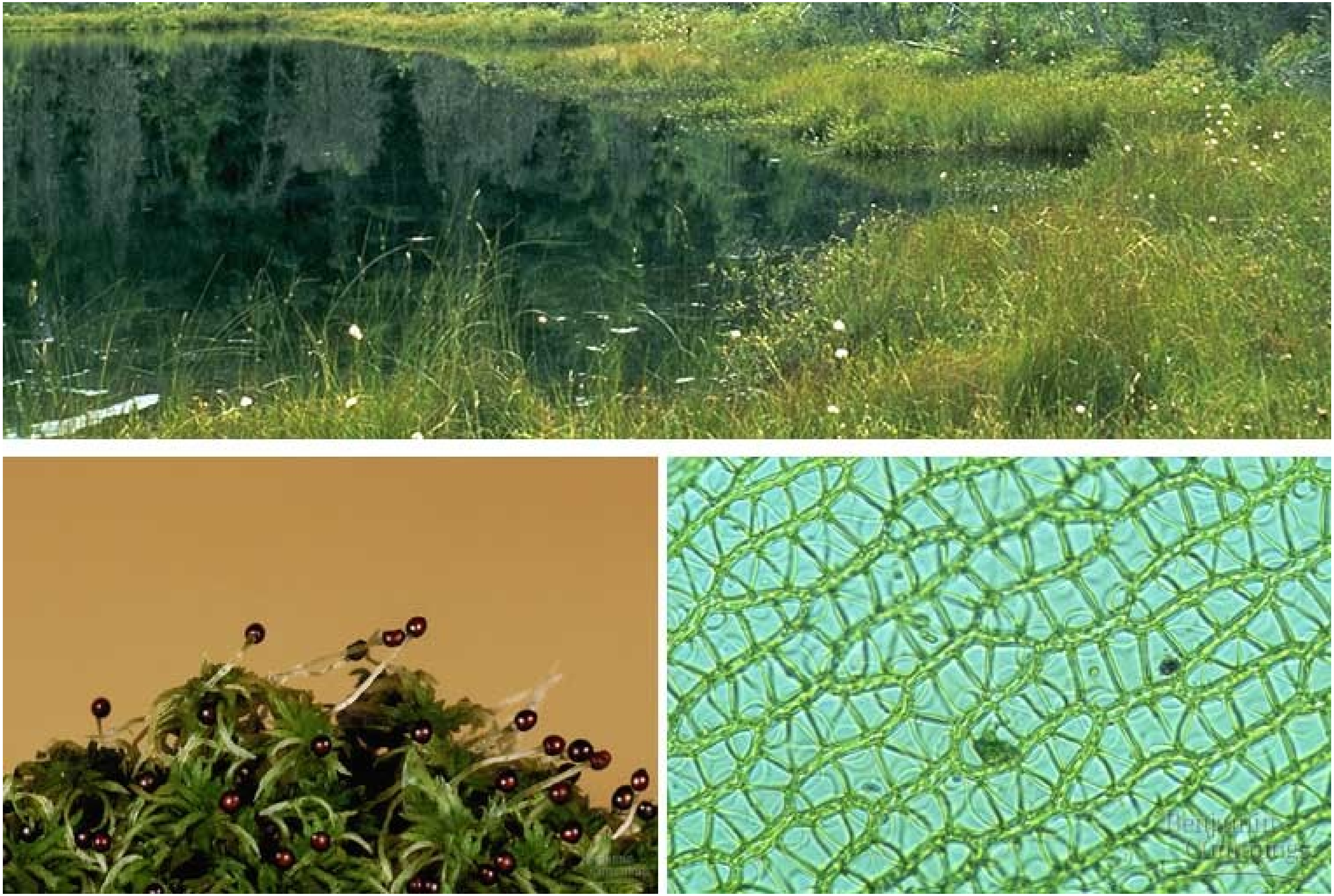
Title: Moss alternation of generations 03-2012.png; Author: Htpaul;
Source: https://upload.wikimedia.org/wikipedia/commons/e/ea/Moss_alternation_of_generations_03-2012.png

A MOSS SPORANGIUM WITH A "SPORE-SHAKER" TIP

Peristome (tooth-like) in the calyptra opens when it dries out and helps to scatter the spores



SPHAGNUM, OR PEAT MOSS: PEAT BOG IN ONEIDA COUNTY, WISCONSIN (TOP), CLOSEUP OF *SPHAGNUM* (BOTTOM LEFT), *SPHAGNUM* THALLUS (BOTTOM RIGHT)



A PEAT MOSS BOG IN NORWAY

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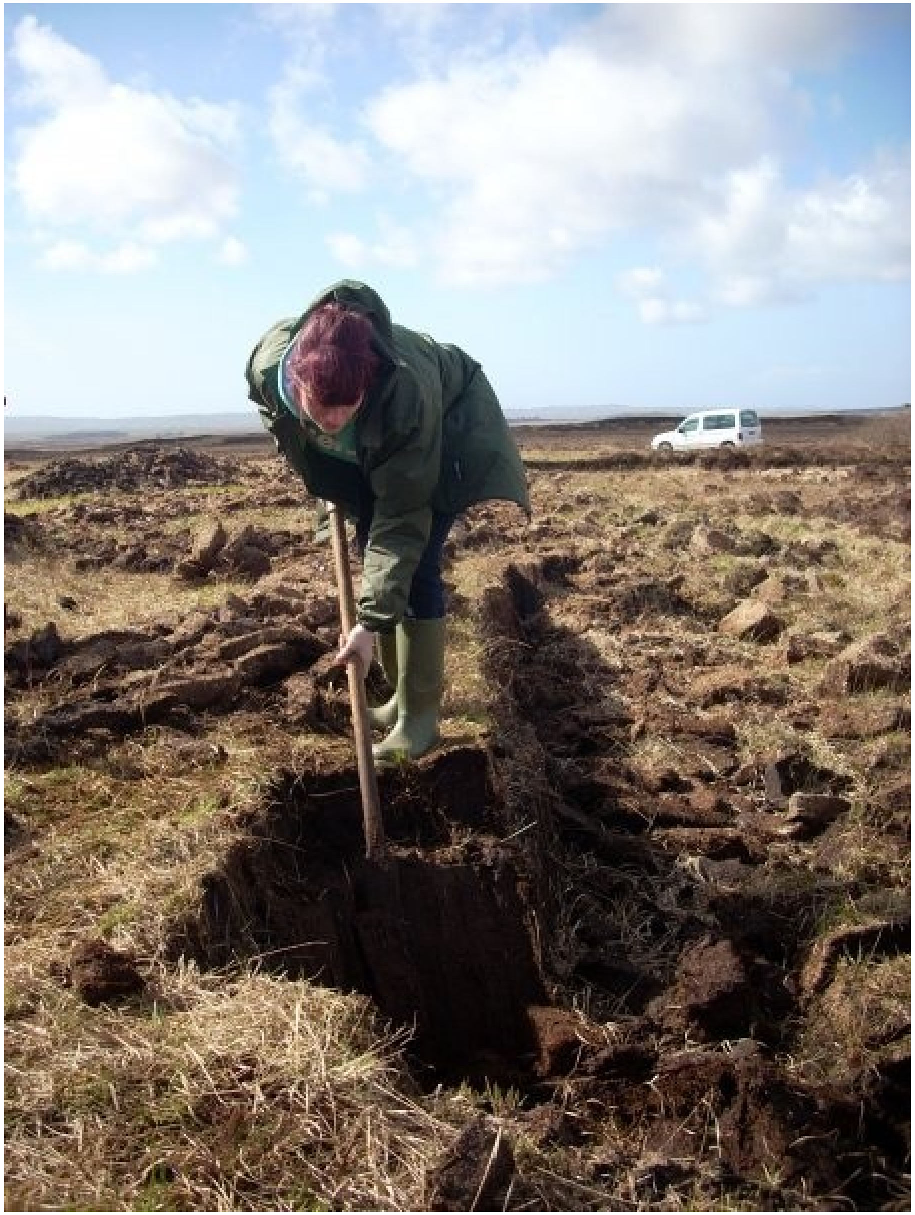
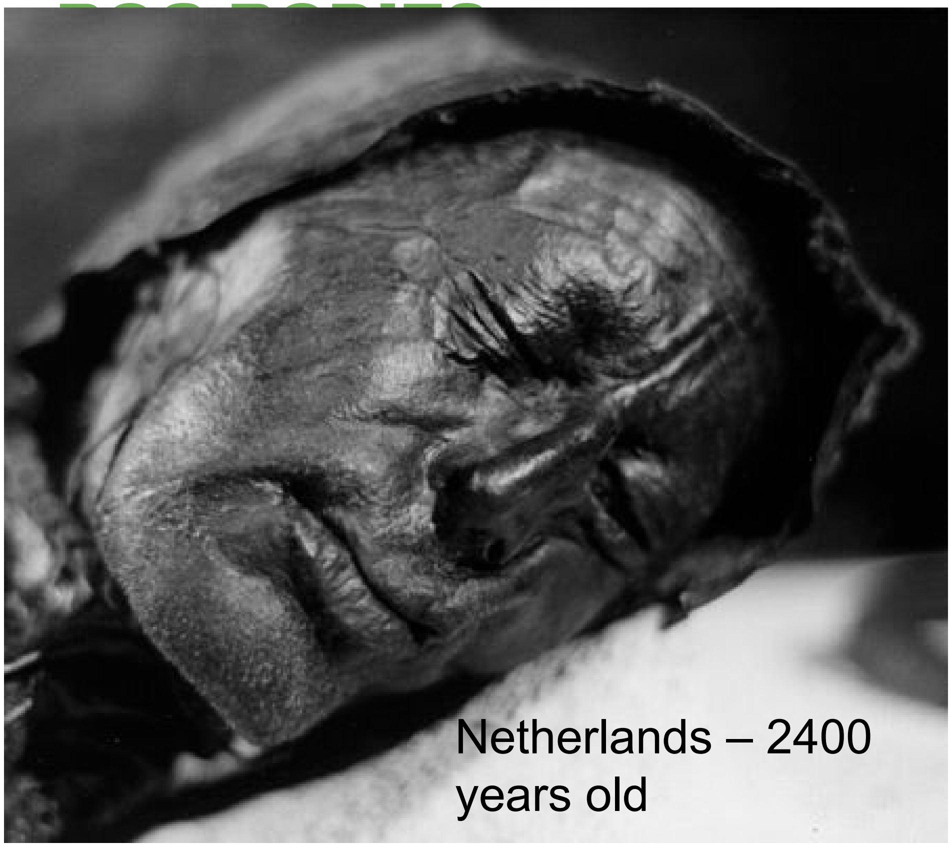
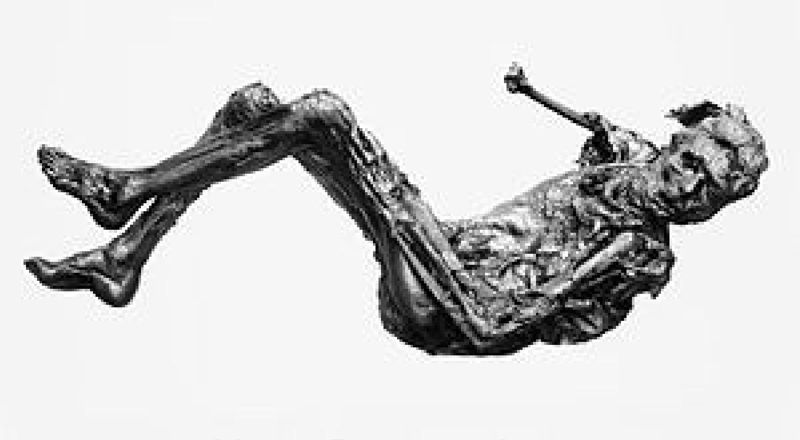


Digging peat moss on the Scottish island of Islay



Netherlands – 2400 years old



Near Denmark – 2700 years old

Tannins + anoxic bog preserves tissue

Intro to 2:50 for lecture

ALGAE VS BRYOPHYTES

- Bryophytes have features not seen in Charophycean algae ancestors.
  - **Life cycle with embryo**, apical growth, always multicellular,
- Charophycean algae have a zygotic life cycle with a one cell diploid zygote
- Bryophytes and other plants have a **sporic life cycle** with alternation of generations
  - Diploid, spore-producing **sporophyte generation**
  - Haploid, gamete-producing **gametophyte generation**

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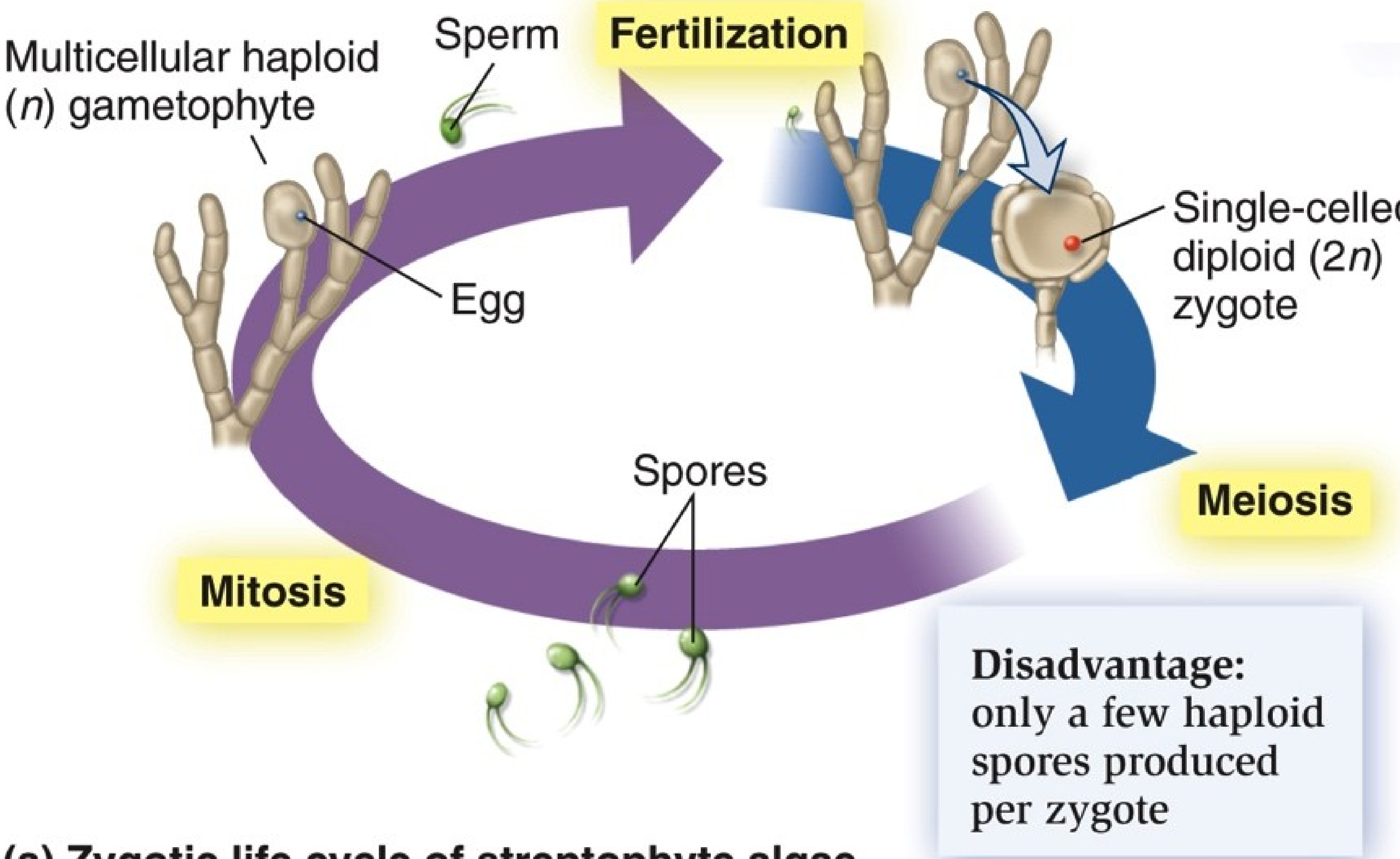

Disadvantage:
only a few haploid spores produced per zygote

(a) Zygotic life cycle of streptophyte algae

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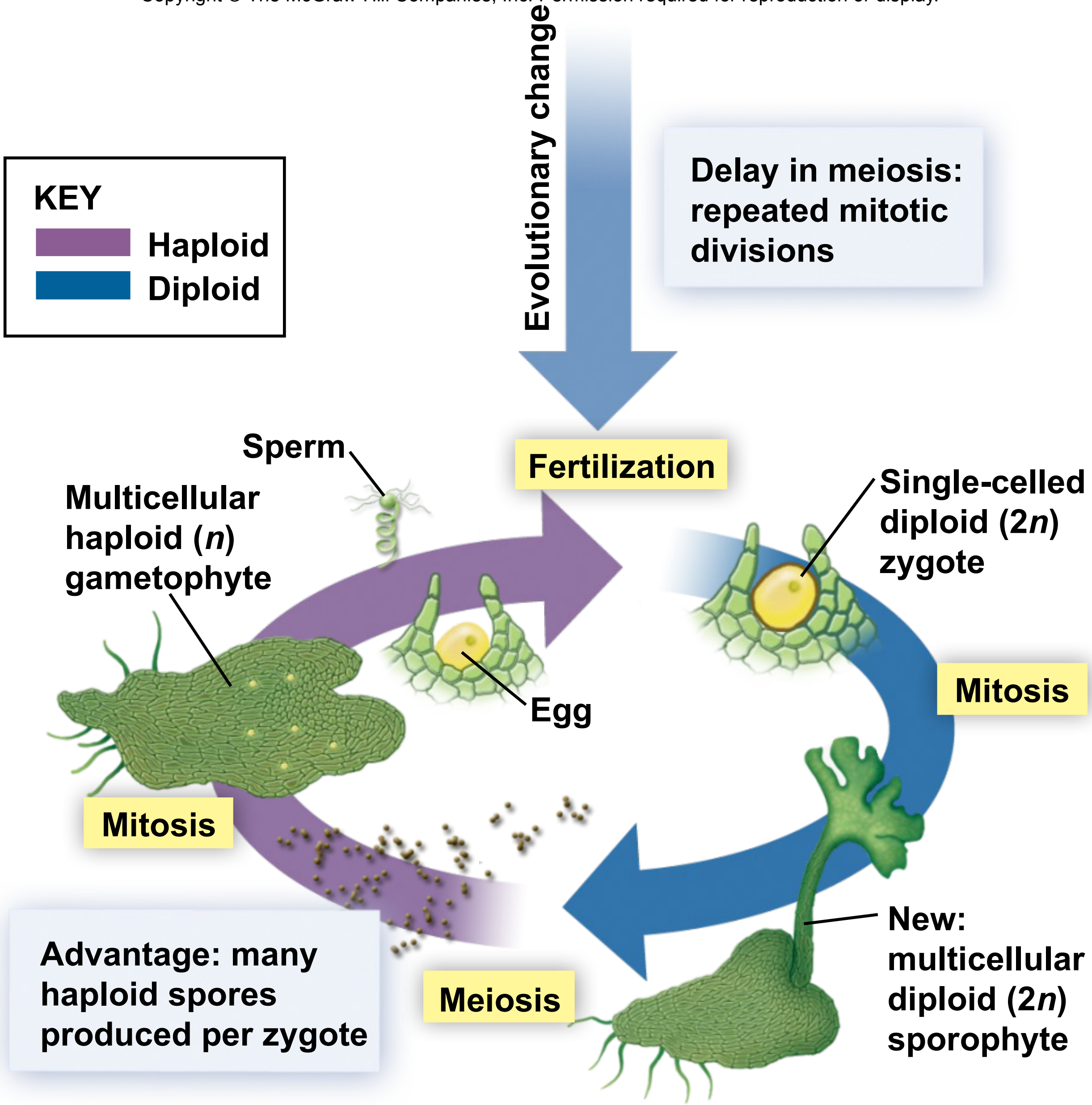
KEY
▨ Haploid
▨ Diploid
Evolutionary change
Sperm
Fertilization
Multicellular haploid (*n*) gametophyte
Single-celled diploid (2*n*) zygote
Egg
Mitosis
Mitosis
Meiosis
New: multicellular diploid (2*n*) sporophyte

Delay in meiosis: repeated mitotic divisions

Advantage: many haploid spores produced per zygote

(b) Sporic life cycle of early plants

DISTINGUISHING BRYOPHYTE FEATURES

GAMETOPHYTES ARE THE DOMINANT GENERATION

- **As opposed to dominant sporophyte generation in other plants**

Sporophytes are **dependent on gametophyte** – small and short lived

- In other plants, sporophytes are independent, large and long-lived (fern, pine tree, roses)

Nonvascular – lacking tissues for structural support and conduction found in other plants

GAMETOPHYTES

ROLE – TO PRODUCE **HAPLOID (N) GAMETES**

Gametophytes are produced by **mitosis from haploid spores**

Gametangia protect developing gametes from drying out and microbial attack

- **ANTHERIDIA** – ROUND OR ELONGATE GAMETANGIA PRODUCING SPERM
- **ARCHEGONIA** – FLASK SHAPED GAMETANGIA ENCLOSING EGGS

Sperm swim (in water) to egg and fuse to form diploid zygote

Zygotes grow into **sporophytes**

ADAPTATIONS TO LIFE ON LAND - DISPERSAL

Multicellular diploid sporophyte generation is advantageous because it allows a single plant to **disperse widely**

- Meiosis produces numerous, genetically variable haploid spores
- Each spore has the potential to grow into a gametophyte

- Learning Catalytics

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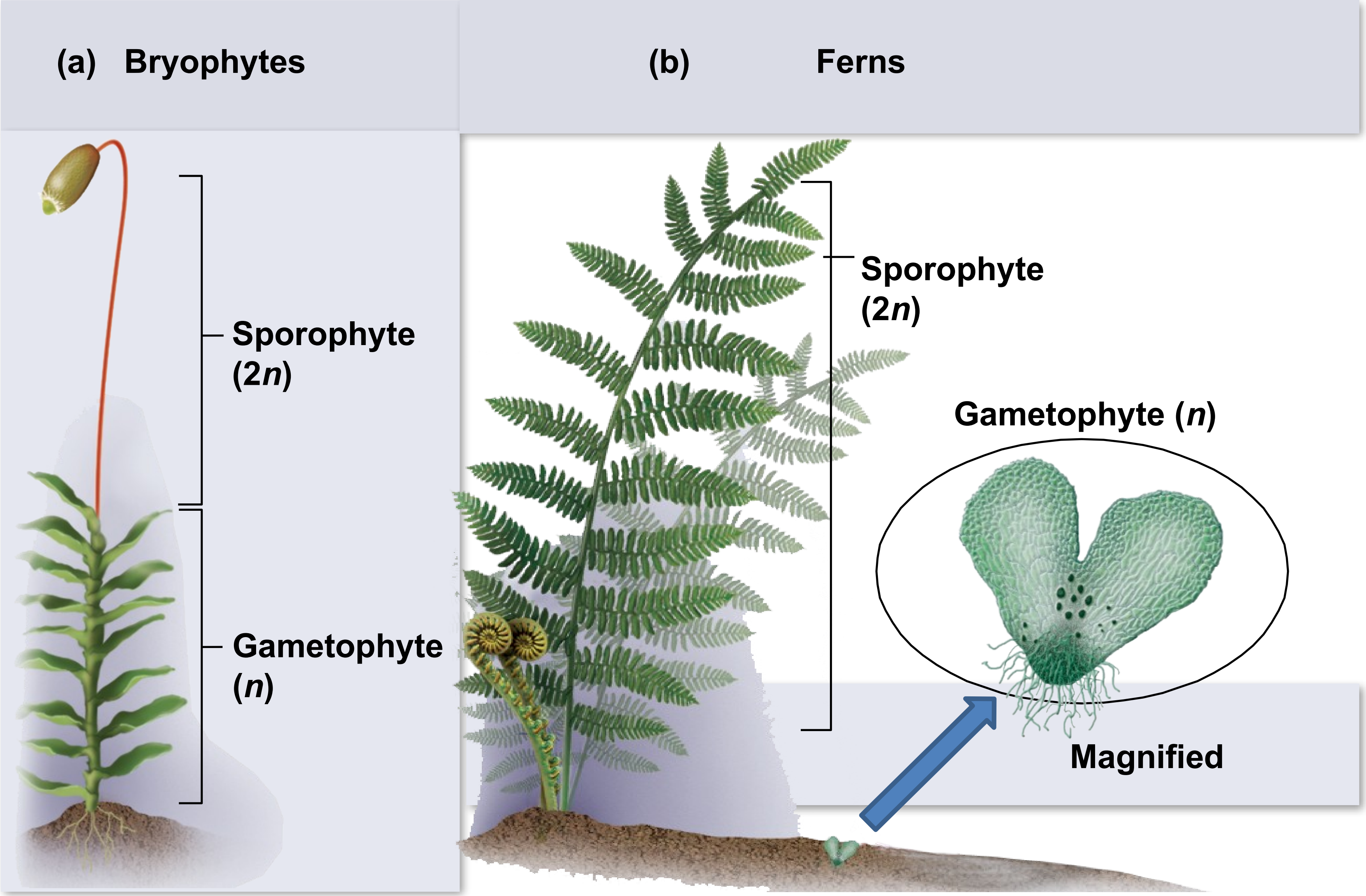

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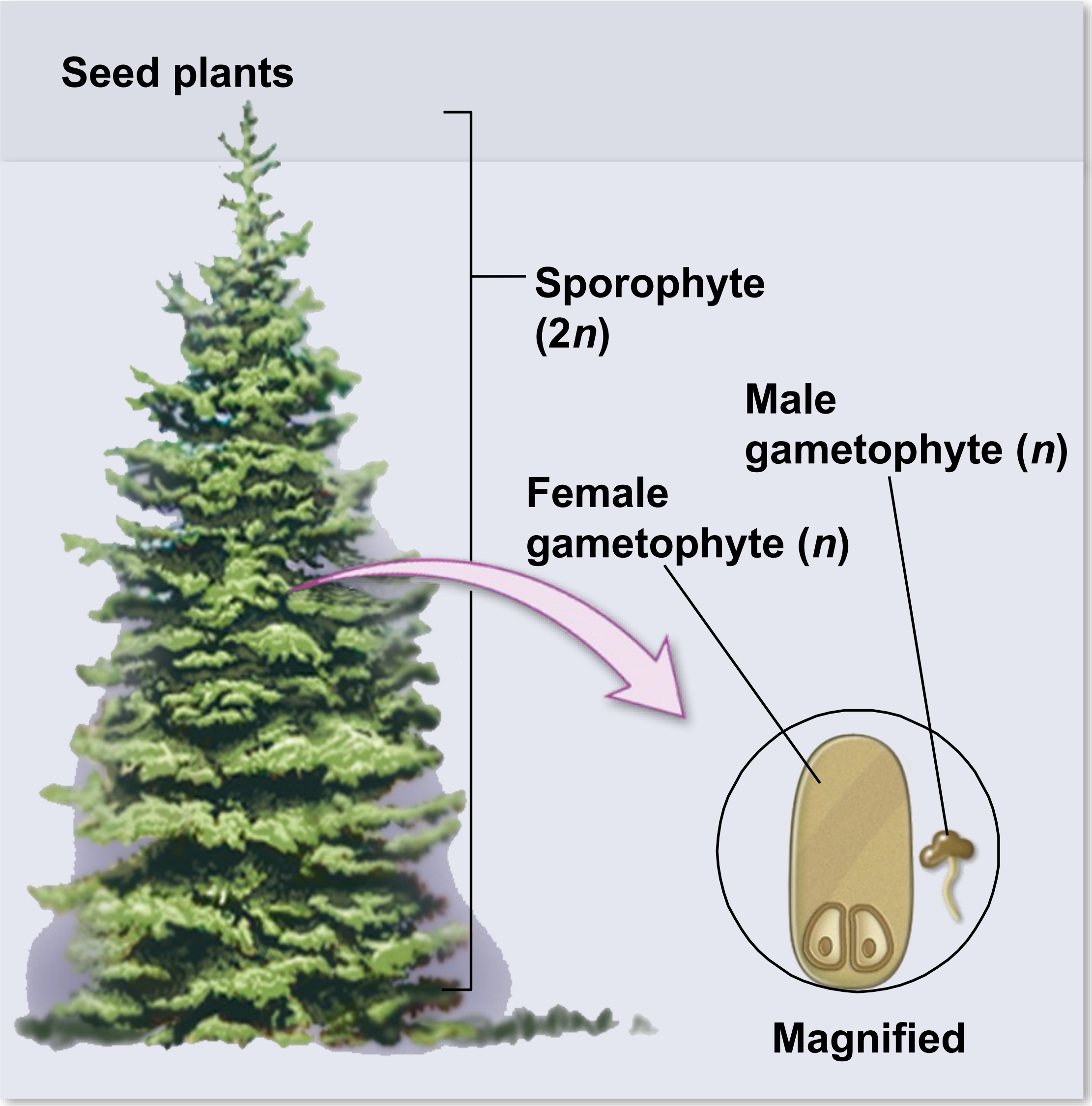

LYCOPHYTES AND MONILOPHYTES

LYCOPHYTES (club mosses) and MONILOPHYTES (ferns): VASCULAR PLANTS that DO NOT produce seeds

Lycophytes – were more numerous and larger in the past but now about 1000 relatively small species (club moss)

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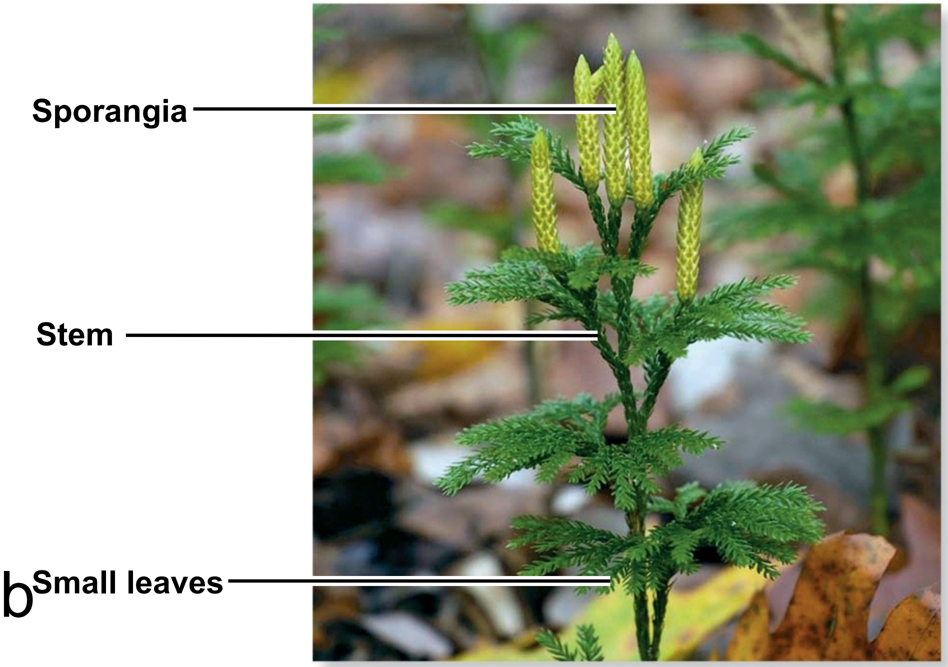

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COMPARISON OF PLANT GENOMES REVEALS GENETIC CHANGES THAT OCCURRED DURING PLANT EVOLUTION

2011 – first complete genome sequence for seedless vascular plants completed by Jody Banks and colleagues

Sequenced the lycophyte (club moss) ***Selaginella moellendorffii***

Scientists have compared this new sequence with other plant genomes to identify **genes associated with major evolutionary transitions** in plants

6,820 gene families are present in all land plants

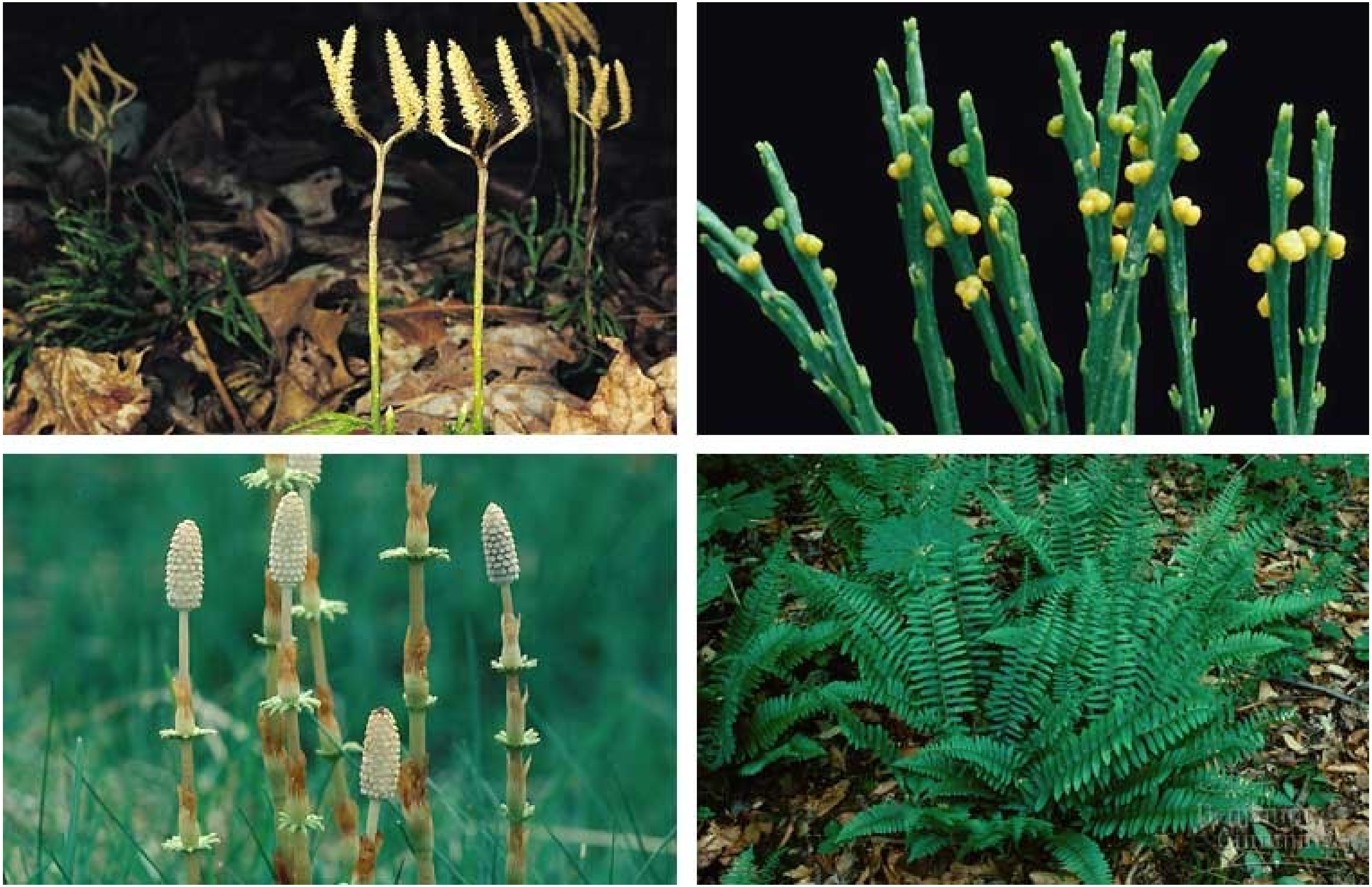
516 genes were gained and **89 genes were lost** during the transition from nonvascular plants (bryophytes) to vascular plants (lycophytes)

- Less genetically complex than the transition from lycophyte to angiosperm

Lycophytes appear to rival the angiosperms in the complexity of their **secondary metabolite** repertoire, with each group displaying unique compounds.

- Lycophyte secondary metabolites may be potential sources of new pharmaceuticals
- Secondary metabolites are organic compounds not directly related to growth, like chemical defense against herbivory. Medicines, flavorings, pigments: human uses of 2nd metabolites.

LYCOPHYTES : CLUB "MOSS" (TOP LEFT); AND MONILOPHYTES: WHISK FERN (TOP RIGHT), HORSETAIL (BOTTOM LEFT), FERN (BOTTOM RIGHT)



- **Monilophytes**
  - About 12,000 species
  - Horsetails, whisk ferns and other ferns

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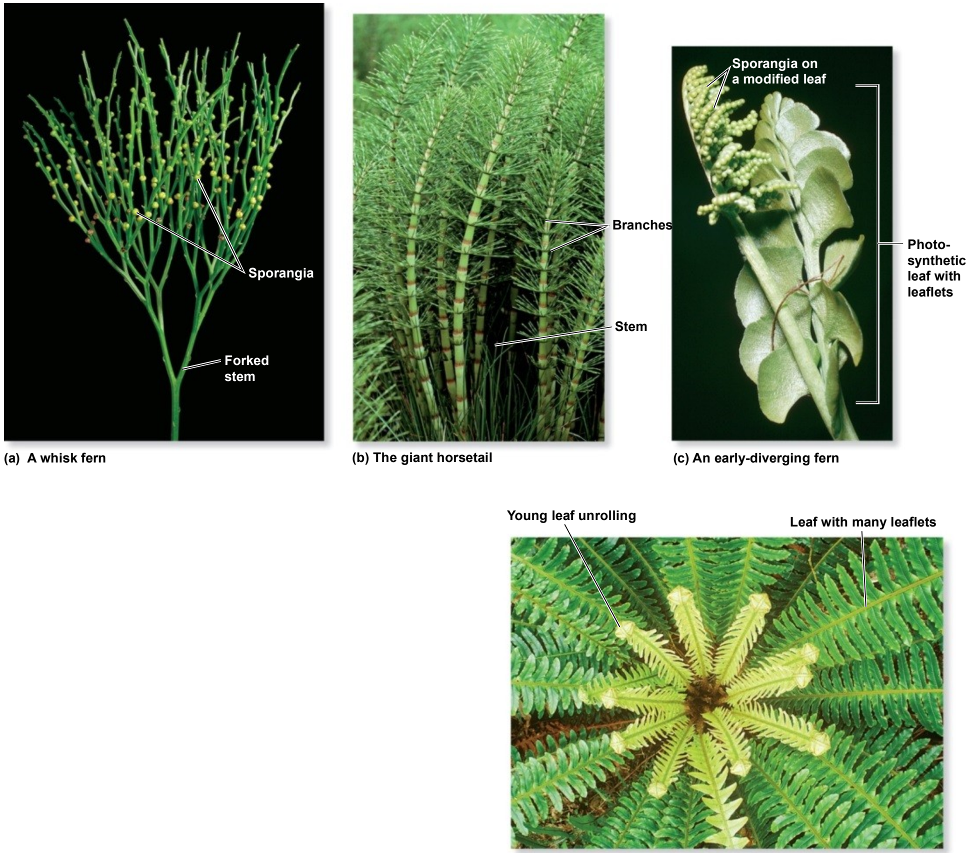

(a) A whisk fern

(b) The giant horsetail

(c) An early-diverging fern

(d) A later-diverging fern

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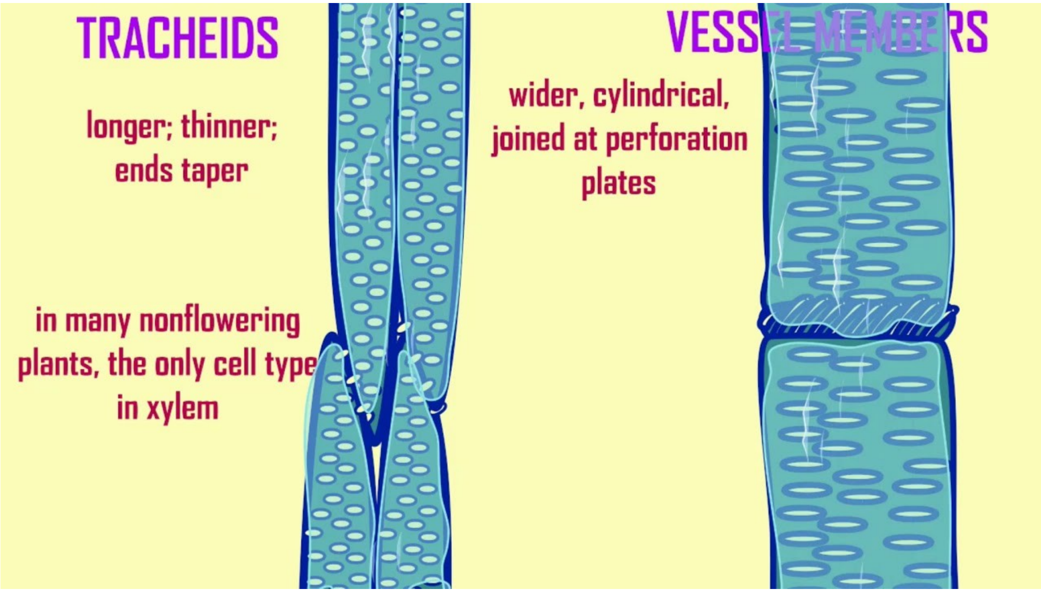
- Lycophytes + Monilophytes + seed-producing plants are all
- **VASCULAR PLANTS (TRACHEOPHYTES)**
  - Possess **TRACHEIDS** for water and mineral conduction and structural support
  - Vascular tissues occur in the major plant organs: **STEMS, ROOTS, AND LEAVES**


TRACHEIDS
longer; thinner; ends taper
in many nonflowering plants, the only cell type in xylem
VESSEL MEMBERS
wider, cylindrical, joined at perforation plates

Start 5-1-23

ROOTS, STEMS AND LEAVES

Stems

- Produce leaves and sporangia
- Contain **PHLOEM AND XYLEM** (contains tracheids and lignin)

Roots

- Specialized for uptake of water and minerals from the soil

Leaves

- Photosynthetic function

ADAPTATIONS TO CONSERVE WATER

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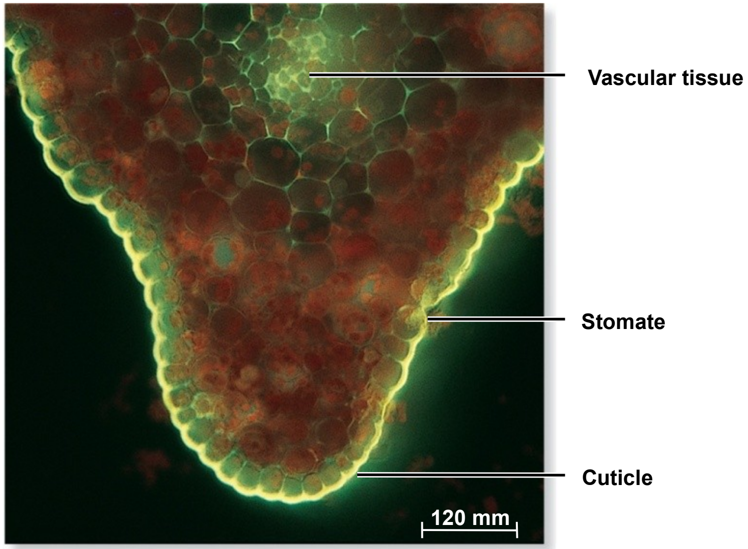
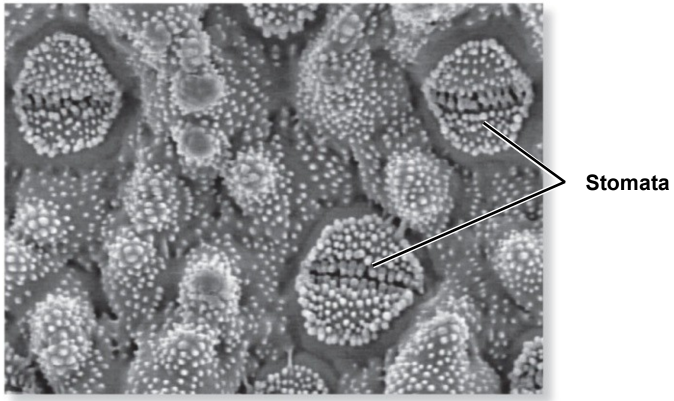
Waxy cuticle present on most surfaces of vascular plant sporophytes –prevents dessication

Cutin (waxy polymer) found in cuticle – helps block pathogens

Stomata – pores that open and close to allow gas exchange while minimizing water loss



(a) Stem showing tracheophyte adaptations



(b) Close-up of stomata

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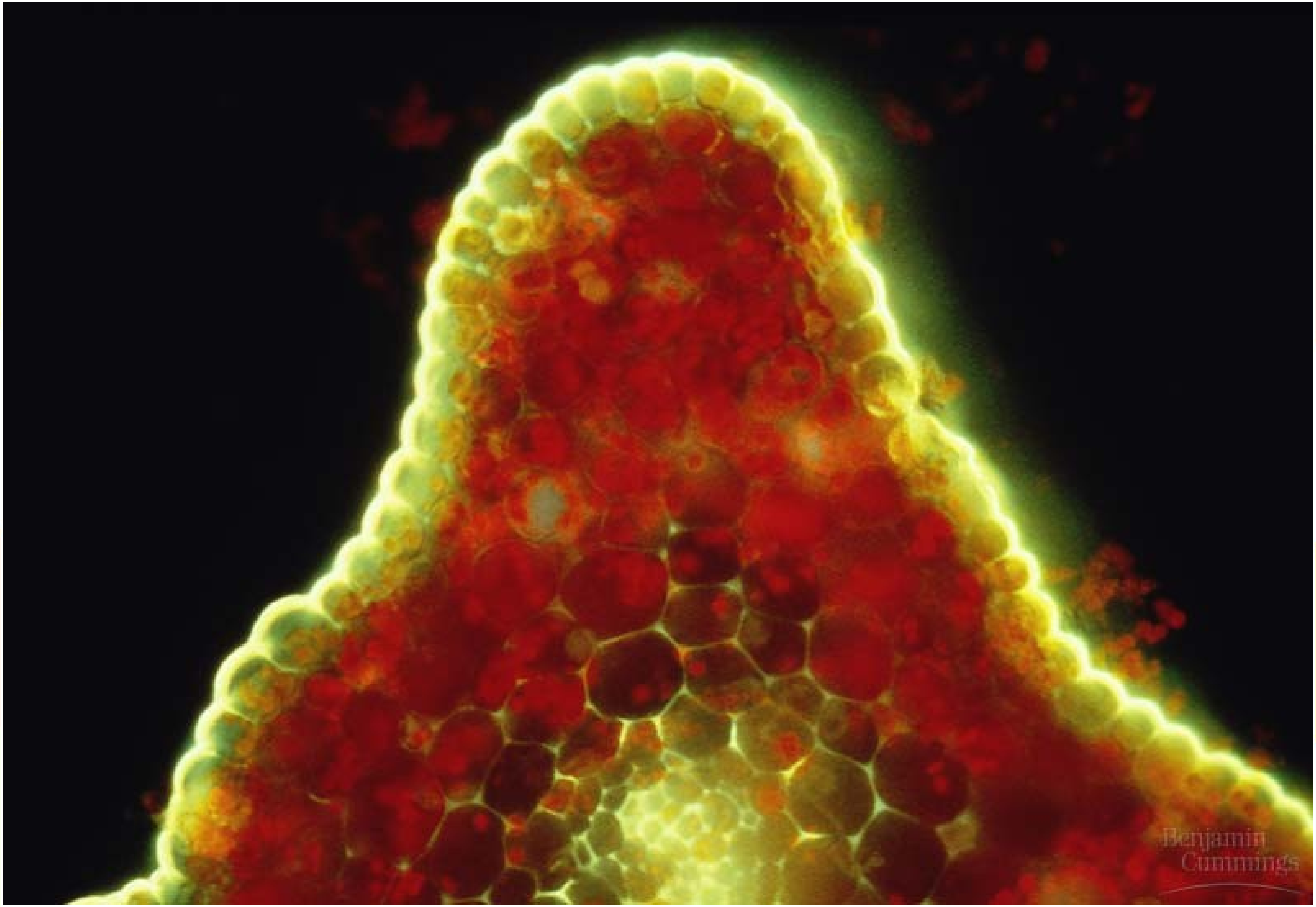
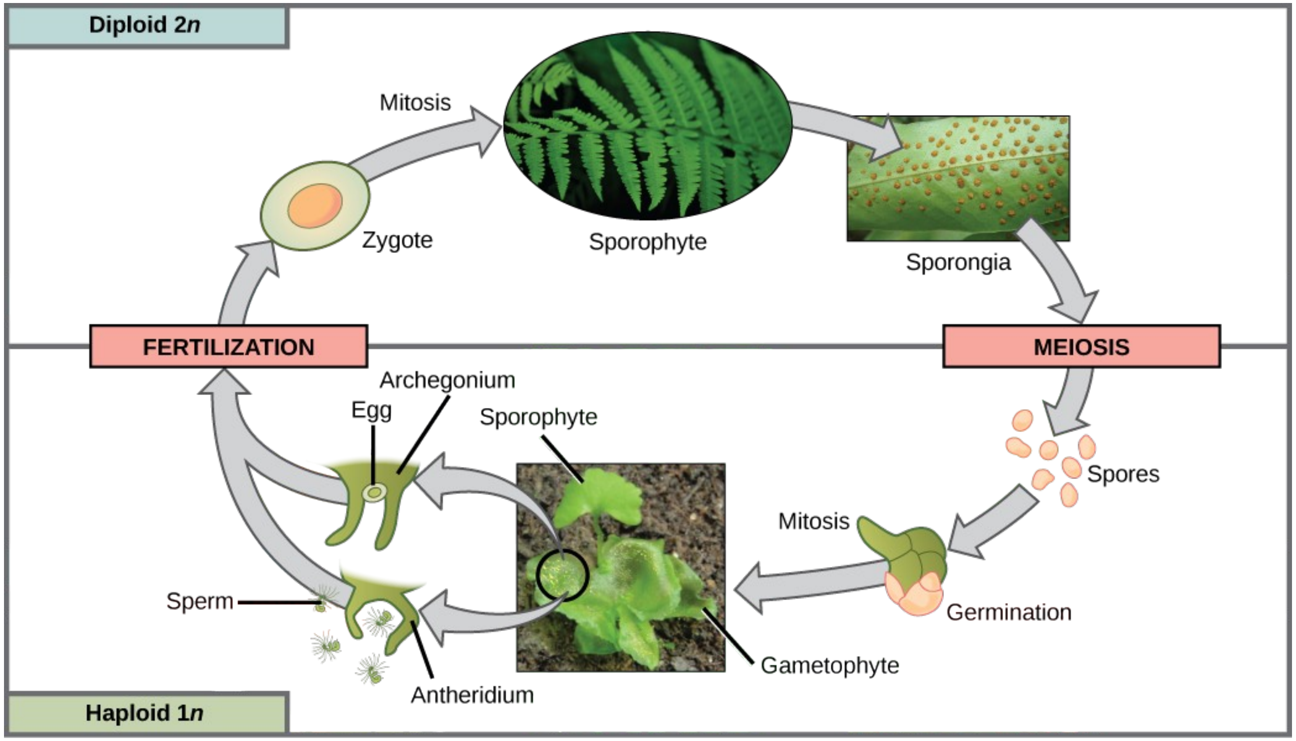
CUTICLE OF A STEM FROM *PSILOTUM* (A MONILOPHYTE)



LIFE CYCLE

- **Lycophyte and monilophyte reproduction is limited by dry conditions, like bryophytes – TIED TO WATER**
- However, if fertilization occurs, lycophytes and monilophytes can produce **many more spores,** due to their larger sporophyte generation
  - Vascular plant sporophytes are dependent upon maternal gametophytes for only a **short time** during early embryo development
  - Stems of vascular plant sporophytes are able to produce branches, forming relatively large adult plants with many leaves

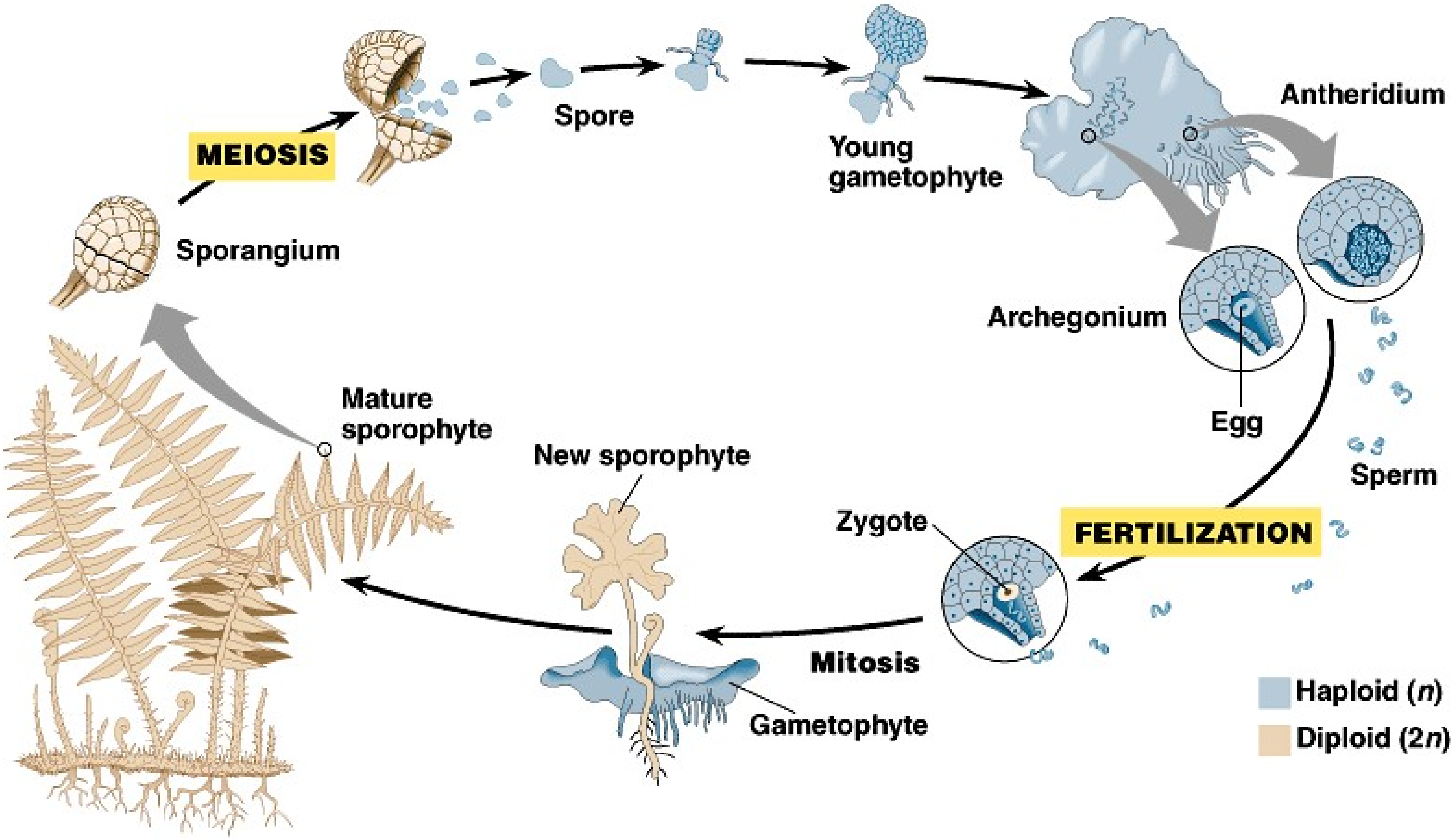
FIGURE 25.22



This life cycle of a fern shows alternation of generations with a dominant sporophyte stage. (credit “fern”: modification of work by Cory Zanker; credit “gametophyte”: modification of work by “Vlmastra”/Wikimedia Commons)

BRYOPHYTE VS FERN REPRODUCTION (0-3:00)

THE LIFE CYCLE OF A FERN



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LIFE CYCLE OF A FERN: MATURE FERN

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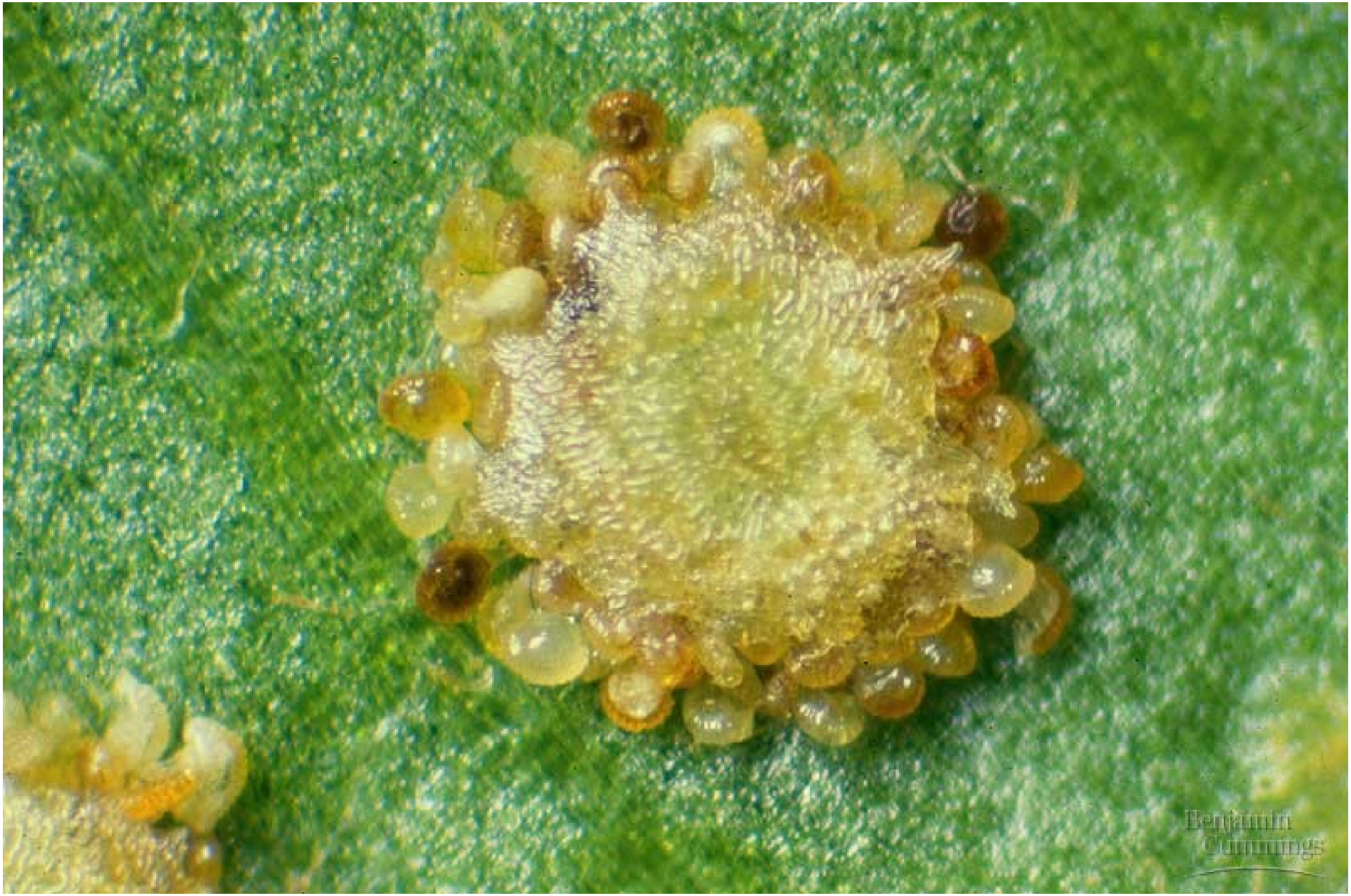
LIFE CYCLE OF A FERN: SORUS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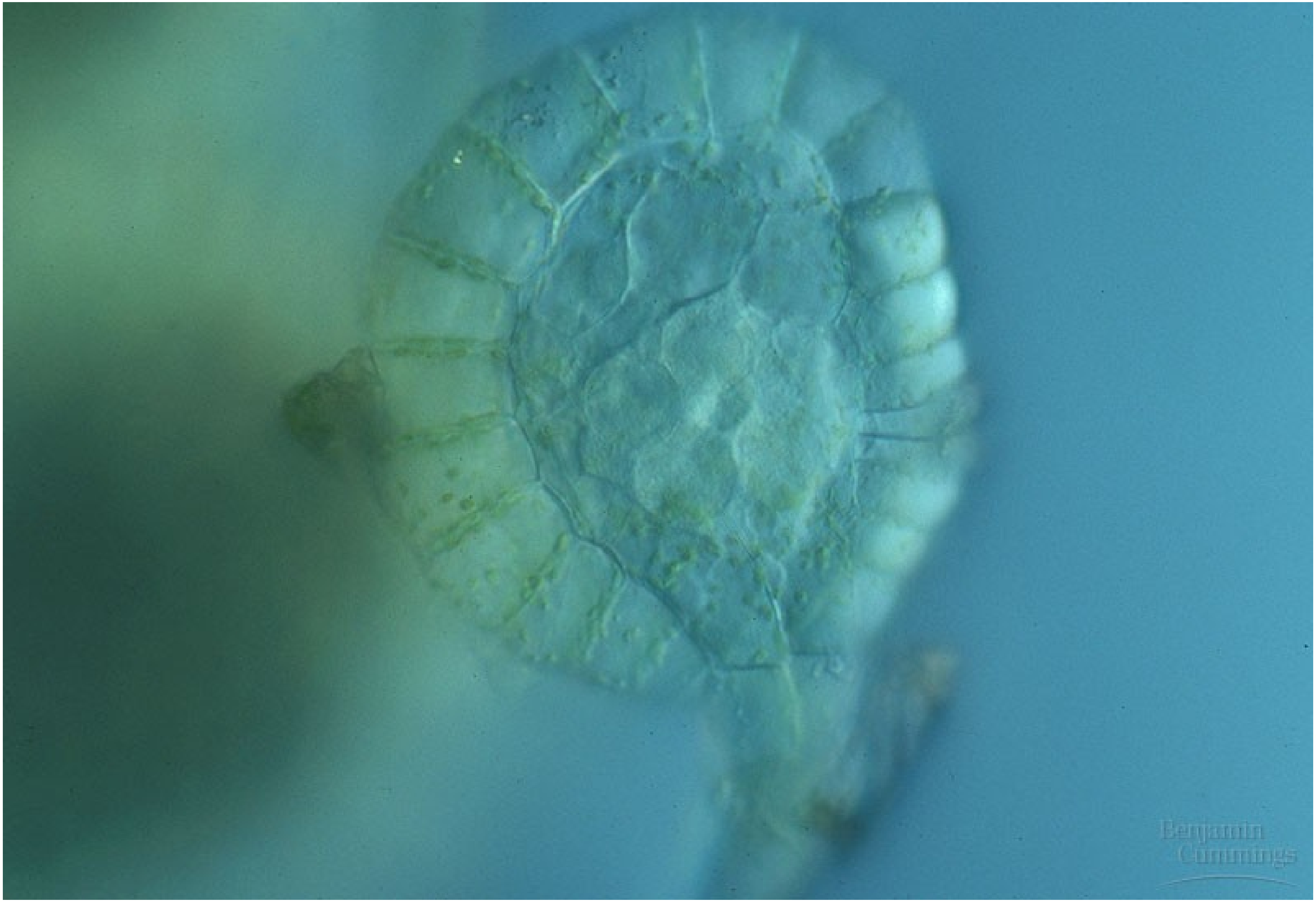
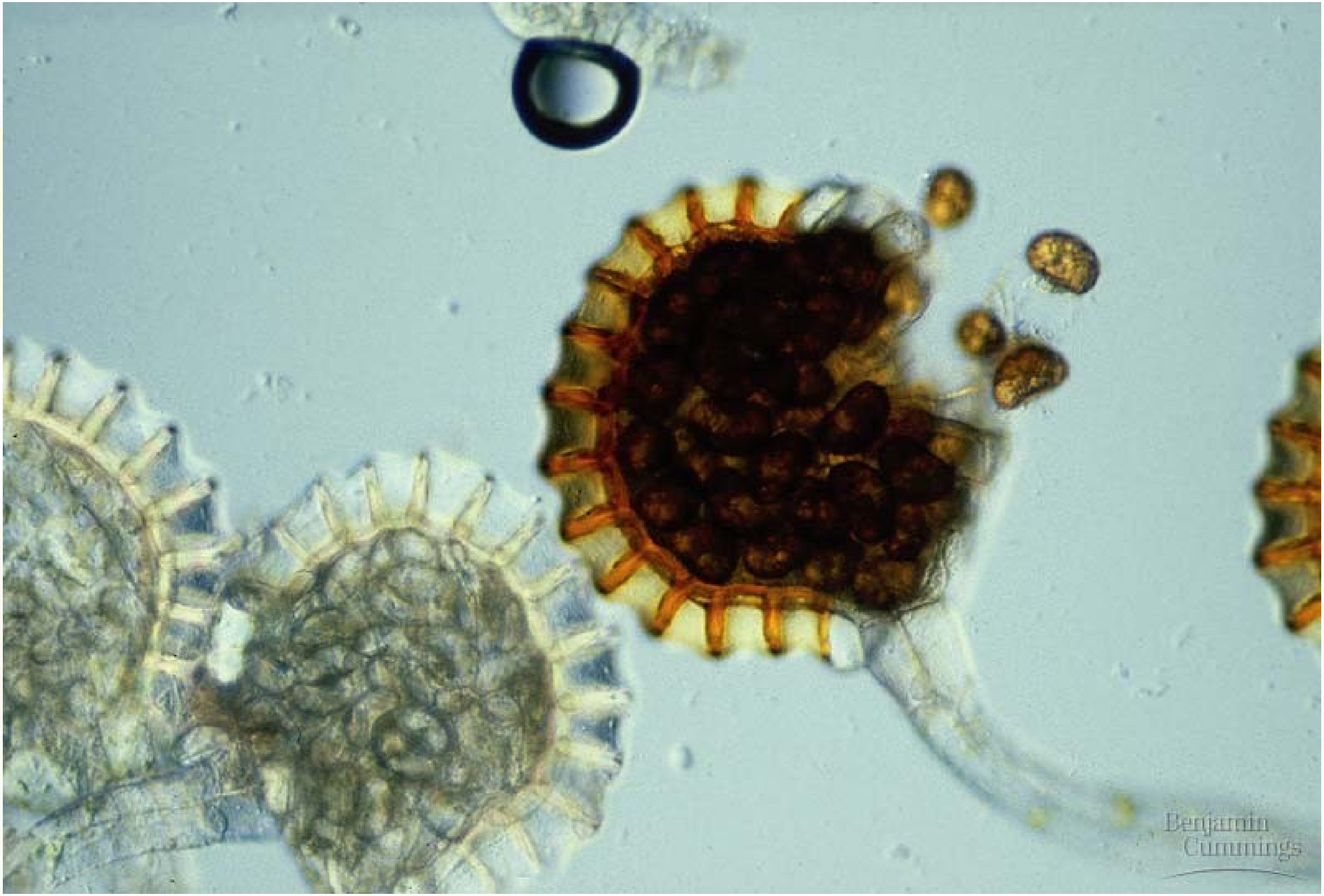
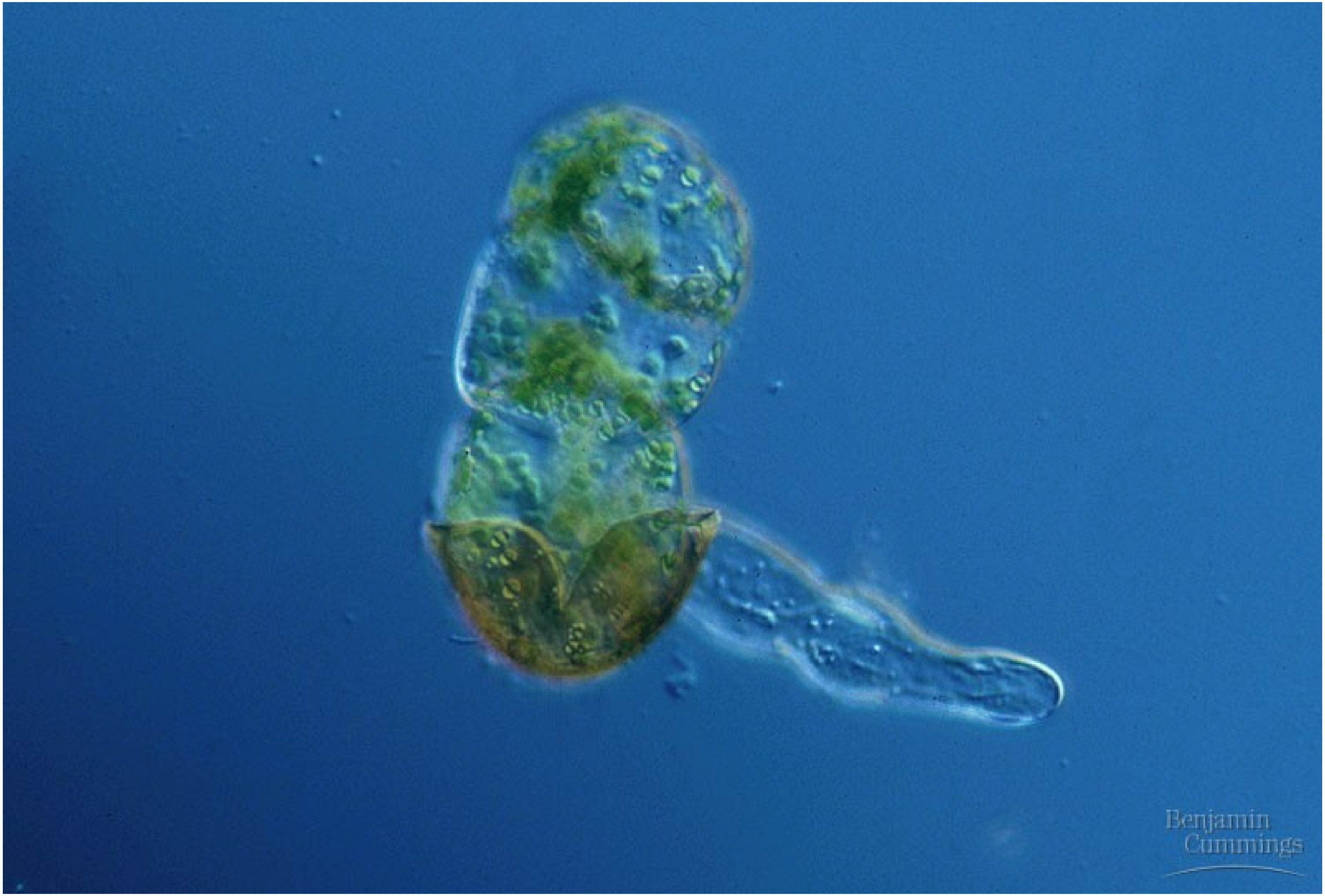
LIFE CYCLE OF A FERN: SPORANGIUM



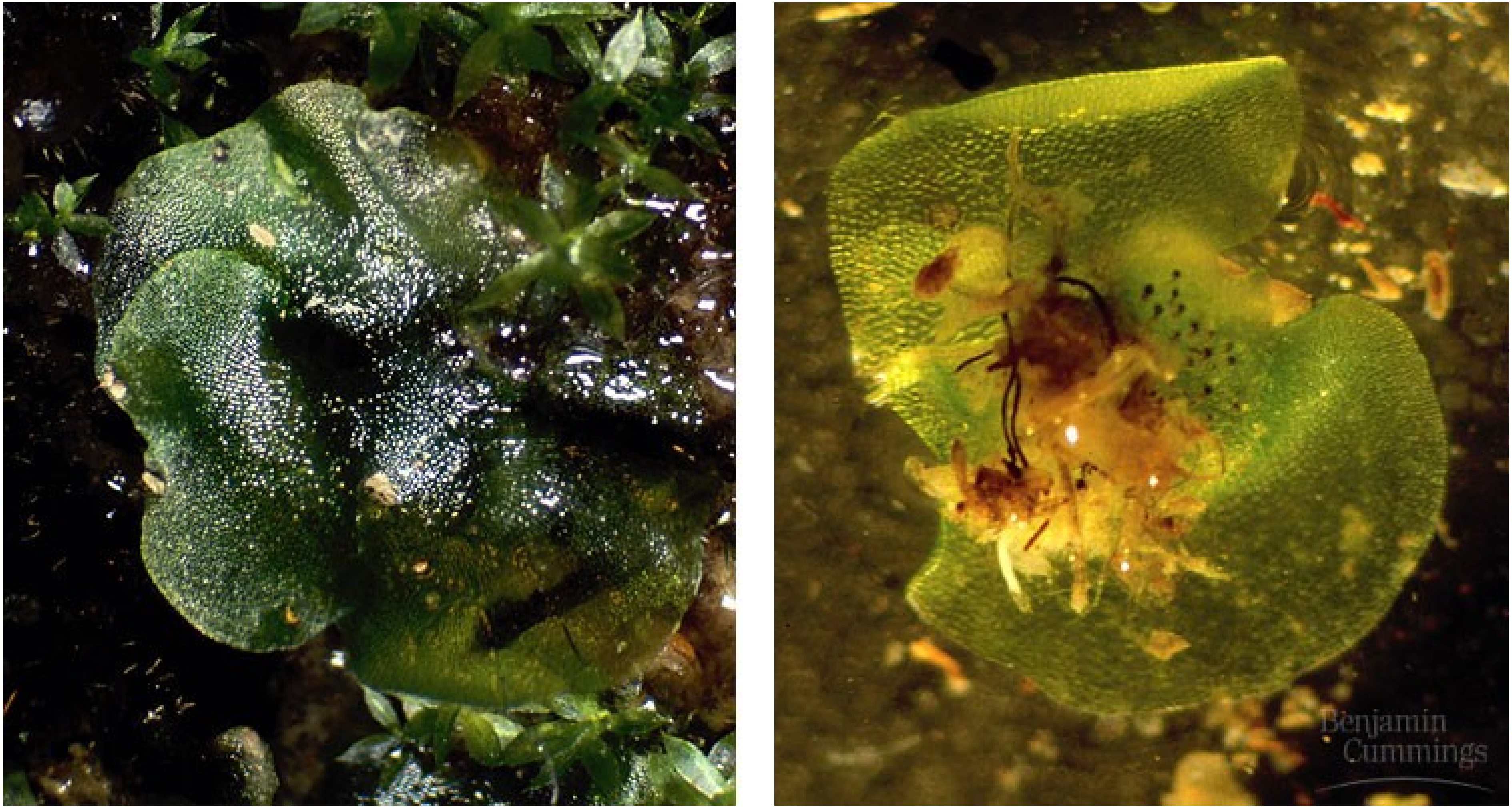
LIFE CYCLE OF A FERN: MATURE SPORANGIUM



LIFE CYCLE OF A FERN: GERMINATING SPORE



LIFE CYCLE OF A FERN: GAMETOPHYTE



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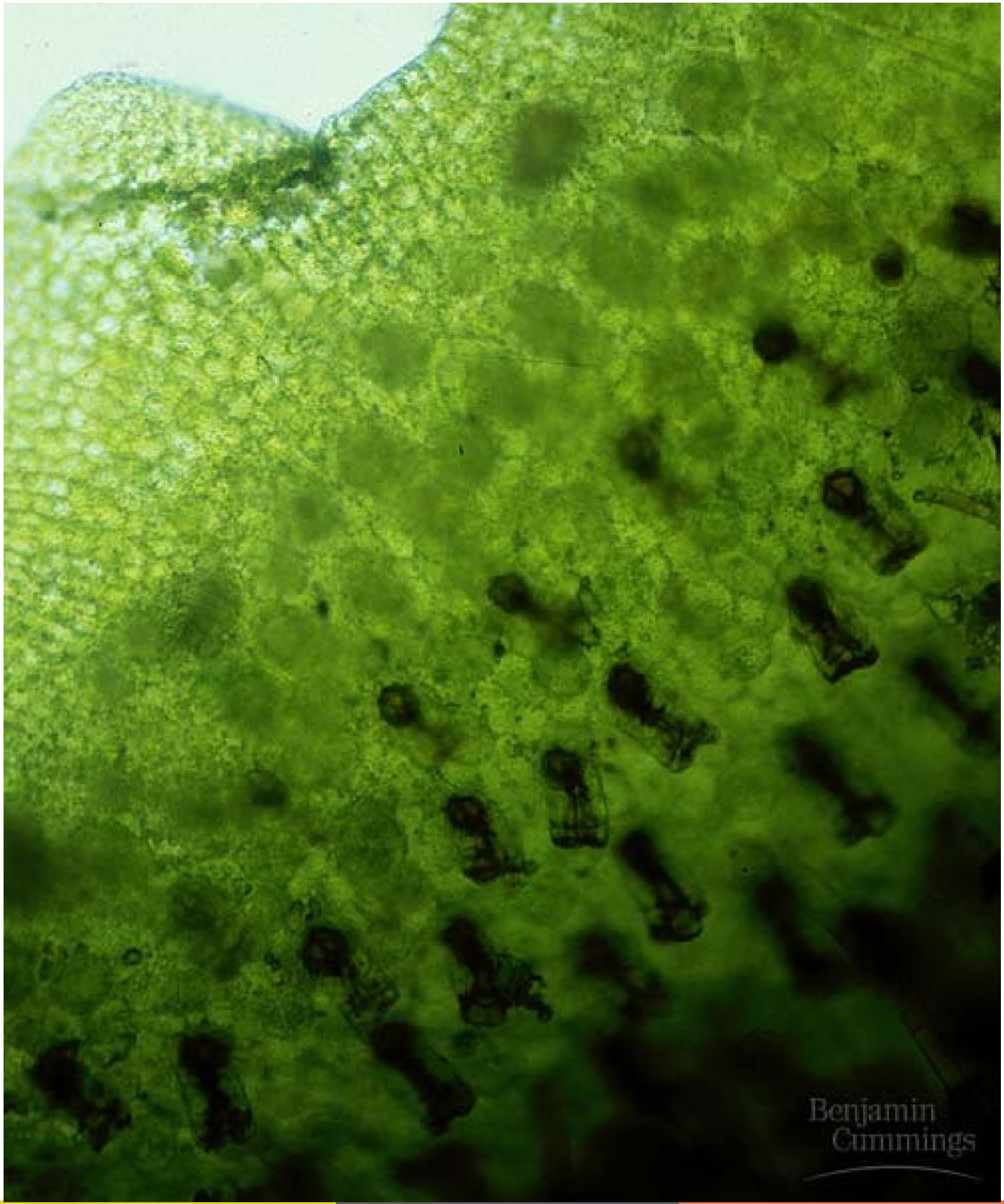
LIFE CYCLE OF A FERN: ARCHEGONIA



LIFE CYCLE OF A FERN: SPOROPHYTES

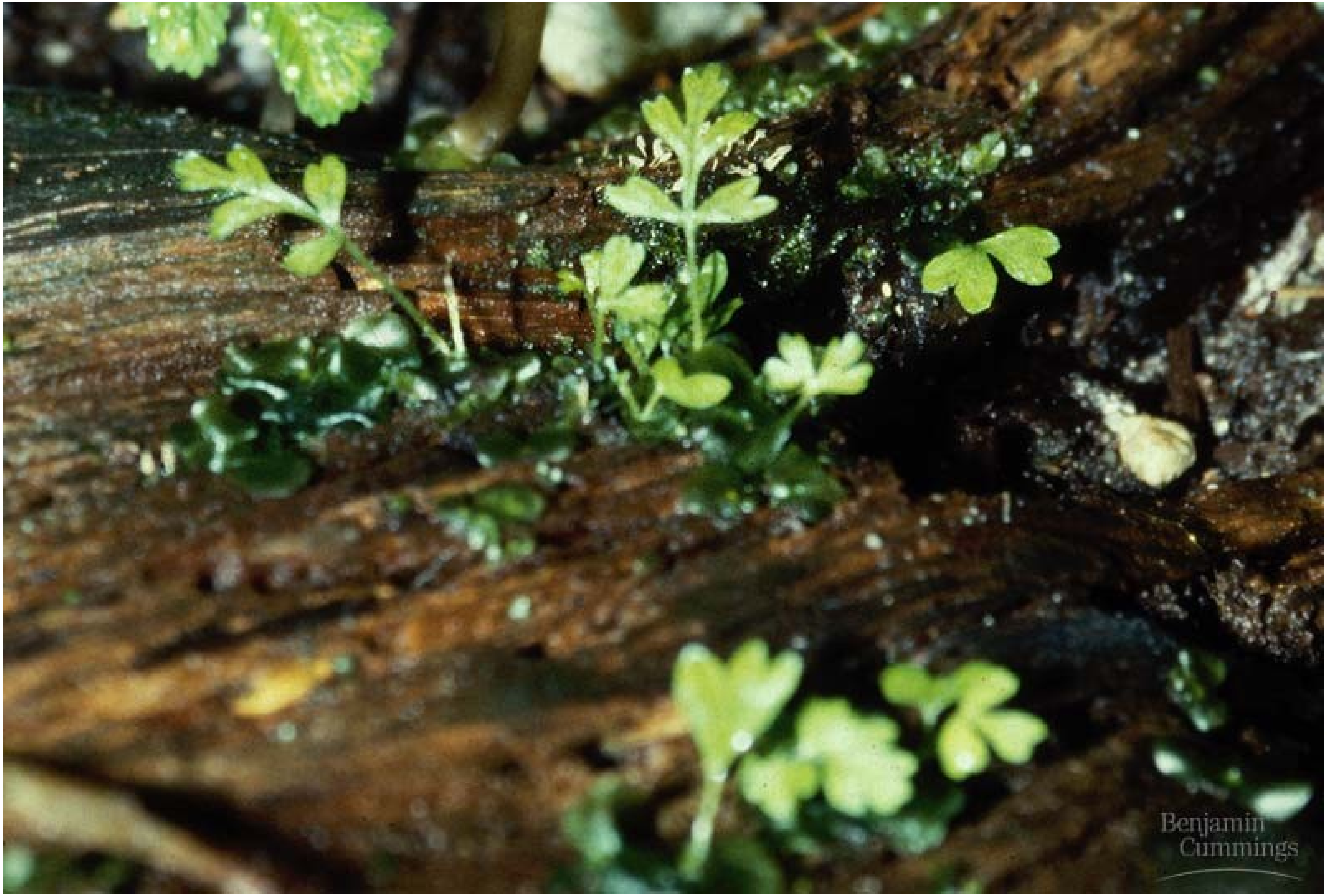
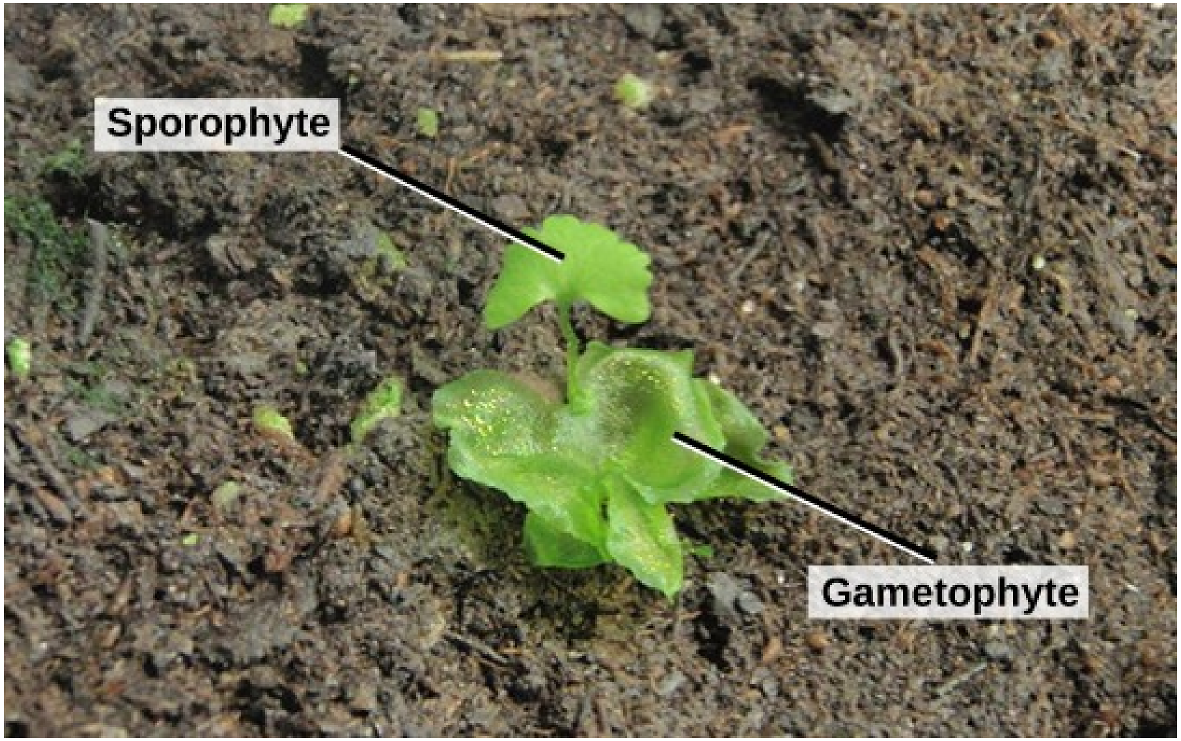


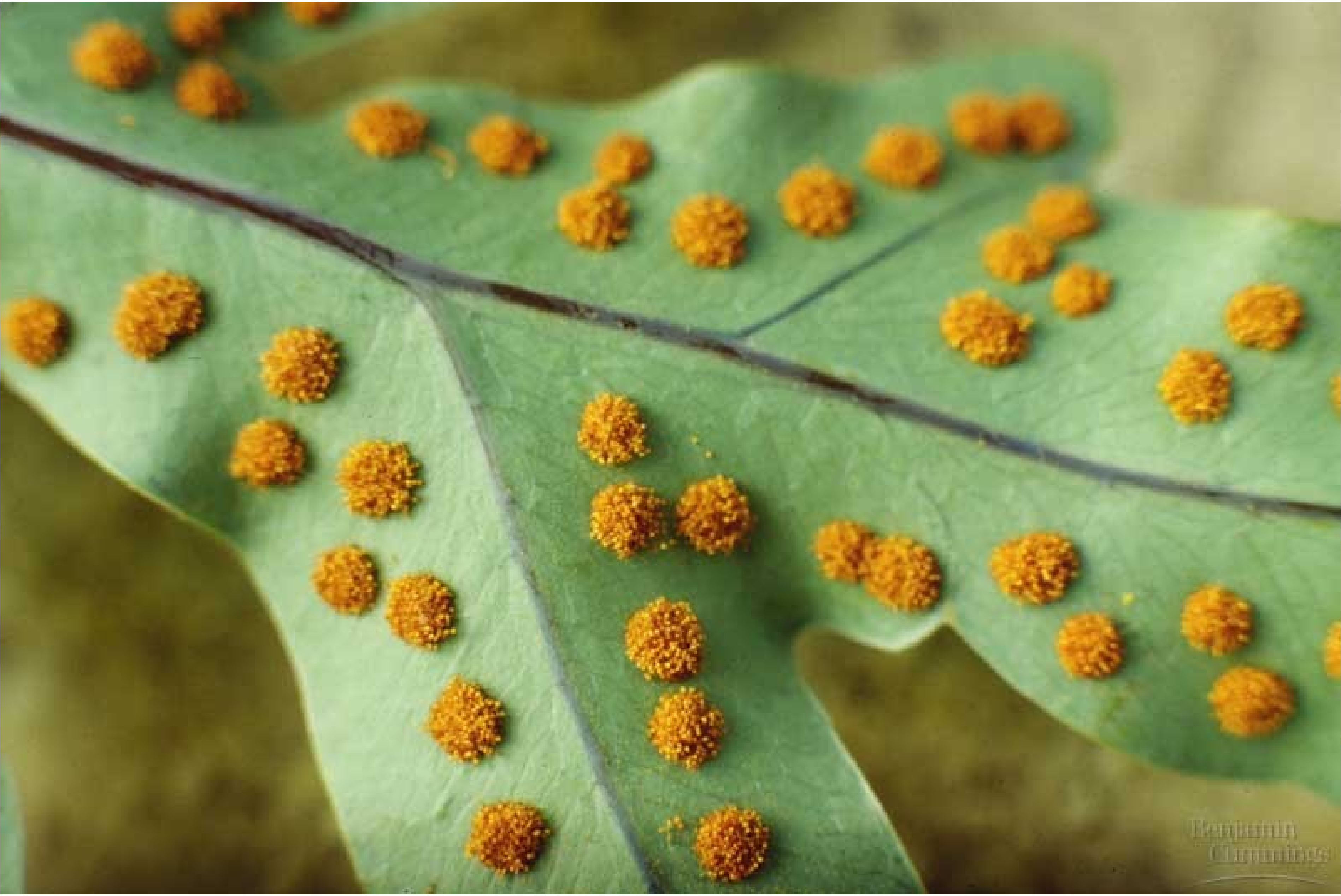
FIGURE 25.24



Shown here are a young sporophyte (upper part of image) and a heart-shaped gametophyte (bottom part of image). (credit: modification of work by “Vlmastra”/Wikimedia Commons)

FERN SPOROPHYLL, A LEAF SPECIALIZED FOR SPORE PRODUCTION

FERN SPOROPHYLL, A LEAF SPECIALIZED FOR SPORE PRODUCTION



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An Evolutionary History of Land Plants

- A billion years ago, the land surface of the earth was bare
  - Except for some cyanobacteria crusts
- Origin of land plants (≈520mya) essential for
  - Development of substantial soils
  - Evolution of modern plants
  - Animals colonizing land (≈440mya)
- Molecular and fossil data show the order plants appeared

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Botanical Society of America, St. Louis, MO., www.botany.org, Steven R. Manchester, University of Florida

THREE STEPS TO PLANTS CONQUERING LAND

1. First land plants arise from ancestors shared with aquatic charophycean algae and **begin to adapt to terrestrial habitats**
2. Seedless plants **transformed Earth's ecology**
3. **The diversification of seed plants and modern angiosperm lineages**

SEEDLESS PLANTS TRANSFORMED EARTH'S ECOLOGY

Liverworts and mosses produce decay-resistant body tissues

  - Could have begun the process of organic carbon burial that helps to **reduce amount of greenhouse gas CO_2** in the atmosphere
  - Helped **enrich soils**

Effects on soil, atmospheric chemistry, and climate **might have been significant** because they could have occurred over large geographic areas and for millions of years before vascular plants became dominant

HOMEOSTATIC NEGATIVE FEEDBACK LOOP IN THE ENVIRONMENT

Modern bryophytes also store CO_2

Under cooler than normal conditions, *Sphagnum* moss grows more slowly and thus absorbs less CO_2, allowing atmospheric CO_2 to rise a bit

Since atmospheric CO_2 helps to warm Earth's climate, increasing CO_2 warms the climate a little

When the climate warms sufficiently, *Sphagnum* grows faster, thereby sponging up more CO_2 as peat deposits

Reducing atmospheric CO_2 returns the climate to slightly cooler conditions

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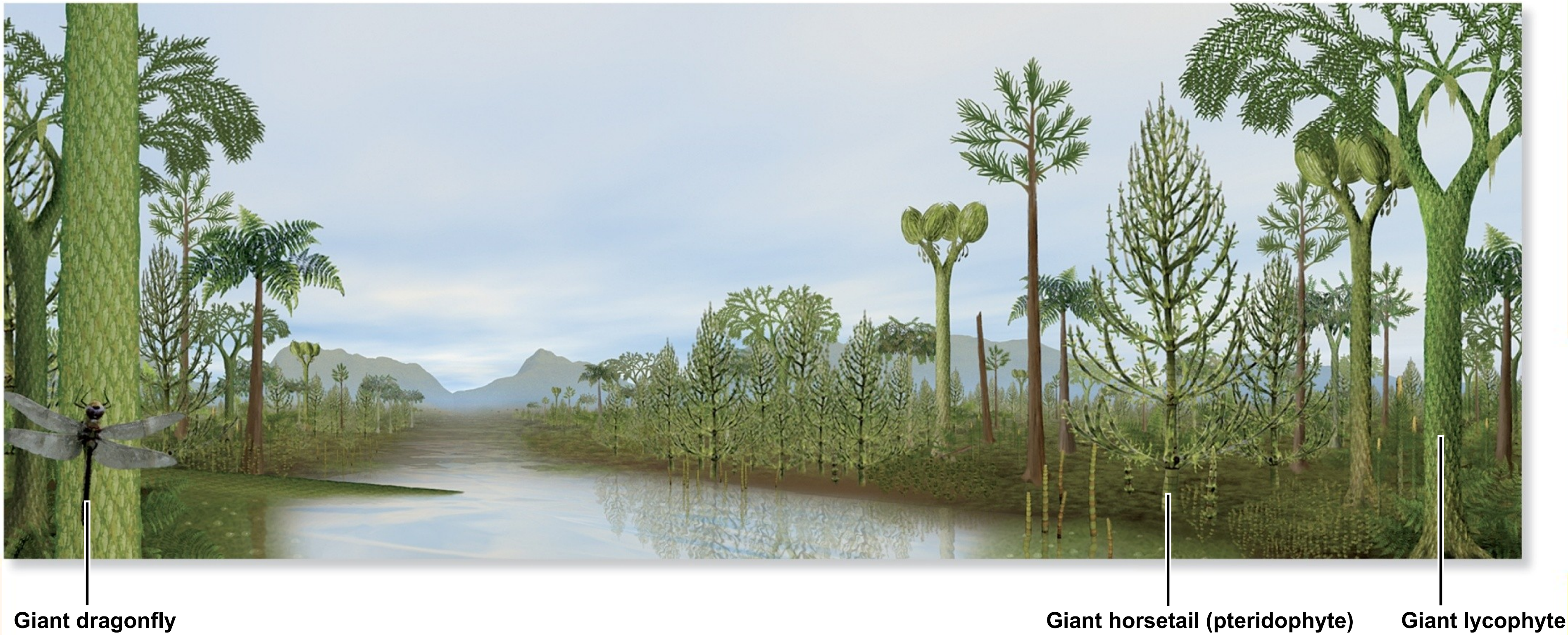

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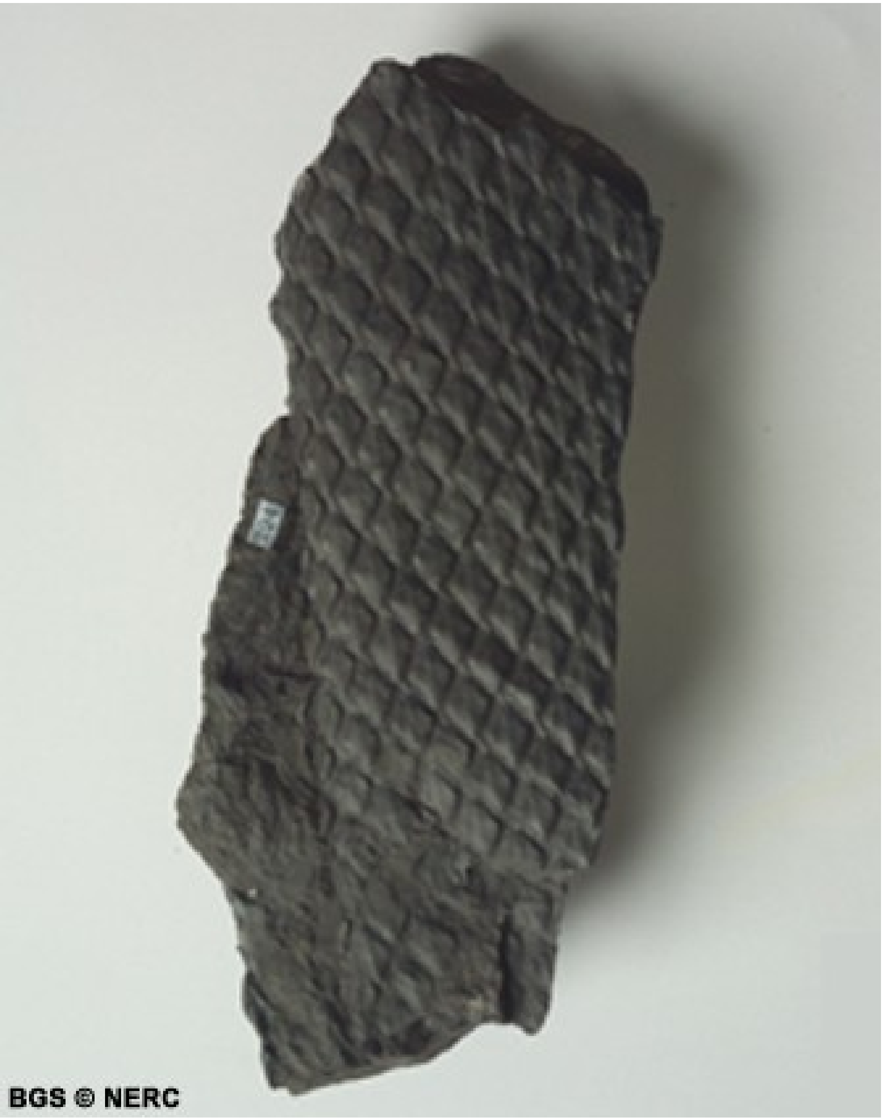
Extensive forests dominated by tree-sized lycophytes, monilophytes, and early lignophytes (plants with wood) occurred in widespread swampy regions during the warm, moist **Carboniferous period** (354–290 million years ago)



Club moss relative fossil from coal seam – *Lepidodendron* sp.
Grew to 30m tall

ECOLOGICAL EFFECTS OF VASCULAR PLANTS

First appear 420-429 mya – Coal Age

Widespread during Carboniferous period (354-290 mya)

Carboniferous plants converted huge amounts of atmospheric CO_2 into **decay-resistant organic material**

Removal of large amounts of the greenhouse gas CO_2 from the atmosphere by plants had a **cooling effect on the climate**

  - Also became drier because cold air holds less moisture than warm air

More **fossils** are found from early vascular plants due to their abundant lignin (rigid complex polymer in wood and bark) and cutin (waxy polymer in plant cuticle)

Carboniferous proliferation of vascular plants was correlated with a **dramatic decrease in CO_2** in the atmosphere

  - Reached the lowest known levels about 290 million years ago

During this period of very low CO_2, atmospheric **oxygen levels rose** to the highest known levels

Seed plants became dominant in the cooler, drier habitats created